THE GENIUS IN THE MICROBE: AN INDISPENSABLE TOOL FOR THE MANAGEMENT OF XENOBIOTIC MEDIATED ENVIRONMENTAL FLUX

An Inaugural Lecture

By

Lucky Obukowho Odokuma
(Professor of Environmental and Petroleum Microbiology,
University of Port Harcourt)

Inaugural Lecture Series

No 87

14 June, 2012

ACKNOWLEDGEMENT

I thank God almighty for being my strength, my shield and my fortress, and for making me who I am.

Words cannot explain the gratitude I have for my wife Mrs. Elizabeth Ekenta Odokuma who has been a pillar of support from the very first day I knew her. She has been a wife, a sister, a friend and a mother to me. She has indeed been a help meet, fit for me. She has been responsible for proof reading 18 of my articles (9th to 27th article). My children Ogaga, Uyota, Eguono and Ohore are indeed a blessing.

I am indeed very grateful to Prof G.S.C Okpokwasili who introduced me to environmental microbiology. He is the genesis of environmental microbiology in the University of Port Harcourt and I am proud to be one of his products.

I thank my father Mr. Emmanuel O. Odokuma and my Mother Mrs. Victoria O. Odokuma for their love, care, dedication and efforts to ensure their first child achieved an enviable position in the academic world.

My siblings (Dr. Ese Odokuma, Mrs. Ovie Alonge, Dr. Igho Odokuma and Dr (Mrs.) Iroro Smith) and their spouses have been very supportive and wonderful. My late sister Mrs. Ochuko Oni, I shall never forget you.

Prof. and Dr. (Mrs.) T. V. Otokunefor and family have been very kind. I am indeed very grateful to both Prof D.D. Datubo Brown (Uncle D.D.) and Prof B.E. Okoli, for their support from the day I became a staff till date. They have both treated me as a favoured son. Prof B. L Nyananyo has been like an elder brother to me.

I am very grateful to Mr. Mutiu Sunmonu, Chairman Shell Exploration and Petroleum Companies in Nigeria (SEPCiN) and Managing Director Shell Petroleum Development Company (SPDC) Nigeria, and his amiable wife Mrs. O. Sunmonu (fondly called Big Aunty) for giving me the opportunity to have corporate industrial experience. Many thanks, to Engr I. C. Okoro, former Manager Environment SPDC, and his successor Mrs. Oby Moore, for their support. I am indeed very grateful to the entire SPDC SODA and HSE (especially Environment) family for their invaluable support. I thank my friends in the Federal and Rivers State Ministries of Environment and National Oil Spill Detection and Regulatory Agency for exposing me to the Government side of the Environment. To my friends Engr and Prof (Mrs.) Emmanuel Nwachukwu of SPDC, late Dr Mrs S.C. Amachukwu and Dr B. Oruwari of Research and Development NNPC and my Orator Prof F.D. Sikoki you have all been wonderful.

I am indeed indebted to staff of the Department of Microbiology and the Faculty of Science of the University of Port Harcourt (both academic and non

academic). You all contributed in making me. My colleagues in the Federal University of Petroleum Resources, Ugbomoro, Effurrun, especially those of the Department of Environmental Sciences, I am very grateful for your support.

I must thank the past and present Chaplains and the entire members of Our Saviour's Chapel University of Port Harcourt. We have been one big happy family.

Finally I must thank all my students especially those who have participated in doing exciting research with me. You have all been wonderful.

DEDICATION

I humbly and lovingly dedicate this lecture to my nuclear and extended family.

THE GENIUS IN THE MICROBE: *AN INDISPENSIBLE TOOL FOR THE MANAGEMENT OF XENOBIOTIC MEDIATED ENVIRONMENTAL FLUX*

The Vice-Chancellor,

Members of the University Council present,

Deputy Vice-Chancellors,

Registrar and other Principal Officers,

Provost, College of Health Sciences

Dean School of Graduate Studies,

Deans of Faculties and School of Science Laboratory Technology

Heads of Administrative and Academic Departments,

Chaplain, Our Saviour's Chapel Uniport,

Colleagues,

Distinguished Guests,

Students,

Friends,

My wife, children and relatives,

Ladies and Gentlemen

PREAMBLE

Sometime in 1985 then Dr G.S.C Okpokwasili taught the 1986 graduating class of the department of Microbiology, University of Port Harcourt a topic in environmental microbiology entitled xenobiotics and biodegradation. This was the beginning of my romance with the terms xenobiotics and microbial infallibility. My classmates often chorused these terms at the beginning of subsequent lectures. I was in year three then. The seed was sown. I decided I was going to study everything about this topic. The way the lecturer pronounced these terms and other related terms (often with a deep voice and making them appear very heavy) increased my appetite for this area of microbiology. To the surprise of my final year (1985-1986) Project supervisor Dr A.U Orjih when I came back for my MSc in 1987, I told him I was going to read Industrial Microbiology (at that time there was no Masters programme in Environmental Microbiology and Industrial Microbiology was the closest to it) so that Dr G.S.C Okpokwasili could supervise me. Dr A.U Orjih a renowned immunologist had hoped that I would work under him during my Masters programme). My final year project had been written into a paper and published in one of the bulletins of the World Health Organization. It was entitled *'The use of chloroquine in Port Harcourt, Nigeria'* (under Medical Microbiology). He was disappointed. Despite this I worked under Dr G.S C. Okpokwasili during my MSc and PhD. My MSc thesis was entitled *'Biodegradation of Oil spill Dispersants'* (1988). We wrote two papers from this document.

My PhD thesis was entitled *'Toxicity of Petroleum Products and dispersed crude oil to microbial systems'* (1991). Together we wrote 10 papers from this document. I am indeed very grateful to my supervisor Prof G.S.C. Okpokwasili who introduced me to the art of writing scientific articles and exposed me to practical environmental microbiology.

Dear Vice Chancellor there exist many definitions of an inaugural lecture. However, I will like to use that of Imperial College London. *A lecture that provides an opportunity to a Professor to present an overview of his/her research career so far, update colleagues on current and future research plans, and introduce their research to wider audiences*. This is what I intend to do today.

INTRODUCTION

In developing a theme/title for my inaugural lecture I have decided to concentrate solely on my area of research Environmental and Petroleum microbiology with emphasis on the following: Bioremediation/biodegradation of xenobiotics, biodeterioration, biomonitoring, development of microbial indicators for pollution monitoring in terrestrial and aquatic systems. Other areas include ecotoxicity / microbial toxicity, bioaccumulation, biocorrosion, atmospheric microbiology, global warming, biomass energy generation, environmental auditing and Impact Assessment.

However to make the story complete I shall include a few other related areas.

The title of my inaugural lecture is as stated" *the genius in the microbe*; *an indispensable tool for the management of xenobiotic mediated environmental flux*"

A genius is something or someone embodying exceptional intellectual ability creativity, or originality, typically to a degree that is associated with the achievement of unprecedented insight. (*Longman Dictionary of Contemporary English* 2007). Microorganisms are exceptional in their physiological abilities. Despite their relative size, simplicity (when compared with other biota) they possess a wide range of genes and enzymes which has provided these organisms with tapped and untapped capabilities. Their genetic flexibility is largely responsible for their variability

in enzyme production and capabilities. Their dexterity and versatility is unrivalled in nature.

The genius in the microbe is a combination of simplicity and complexity of enzyme and genetic composition of these evolutionary simple organisms. As a result of the vastness in microbial variability I shall limit this discuss to the role played by prokaryotic microorganism (bacteria) of environmental (not health) significance leaving out eukaryotic microorganism (fungi, protozoa, helminthes and algae) and viruses.

Prokaryotic organisms include all the bacteria (archibacteria and eubacteria). The cyanobacteria formally called blue- green algae are also included in this group.

A xenobiotic is a chemical which is found in an organism but which is not normally produced or expected to be present in it. It is foreign to the organism. It can also cover substances which are present in much higher concentrations than are usual. Specifically, drugs such as antibiotics are xenobiotics in humans because the human body does not produce them itself, nor are they part of a normal diet. The term xenobiotic is also used to refer to organs transplanted from one species to another. However, for this discourse we are going to limit it to the former definition. Xenobiotics include man made synthetic compounds such as component of pesticides, plastics, drilling fluids antibiotics, petrochemicals, heavy metals etc

Some xenobiotics are resistant to degradation (persistent/recalcitrant). For example, they may be synthetic organochlorines such as plastics and pesticides, or naturally occurring organic chemicals such as polyaromatic hydrocarbons (PAHs) and some fractions of crude oil and coal. However according to Martin Alexander's theory of microbial infallibility (Atlas and Bartha 1998), it is believed that microorganisms are capable of degrading almost all the different complex and resistant xenobiotics found on the earth if provided with the right environmental conditions. Many xenobiotics produce a variety of biological effects, which are used when they are characterized using bioassay.
The term flux has many meanings but for this lecture we are going to define it as the rate of continuous change of matter, flow or movement of matter or energy in the environment or simply environmental (physicochemical and biological) changes.

ENVIRONMENTAL STABILITY (EQUILIBRIUM)
Our environment is our surroundings. Our surroundings are made up of biotic and abiotic components. The biotic components include all life forms unicellular organisms (eubacteria archibacteria, cyanobacteria, algae, protozoa, helminths etc) ad multicellular organisms (plants, animals and humans). The abiotic components include the non-living components such as terrestrial system (soil, rocks, volcanoes, mountains etc), aquatic systems (ponds, ground water, lakes, rivers, sea, estuaries oceans etc) and

aerial or atmospheric systems (air, wind, rainwater etc).
Sometimes included as unicellular organism are the viruses which are not living in the sense that they do not perform classical activities of living organisms(such as reproduction, nutrition, growth in the biological sense of these words) but behave as living organisms (they populate their hosts by replication and posses nucleic acids which are present in organisms).

Both biotic and abiotic system serves as habitats (homes) for bacteria. For instance some bacteria live in other bacteria, while bacteria have been found in every ecosystem on earth.

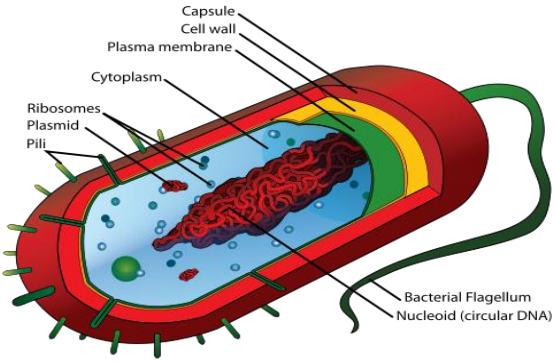


Fig 1.0: A typical bacterial cell

Our environment is a very important resource. The environment of the earth is different from any other planet in our solar system. Earth environment produces and sustains life. Thus, maintaining the

biological and physicochemical integrity of this environment will ensure the sustenance of life. The earth has internal regulatory mechanisms which maintain this equilibrium (constancy e.g. CO_2, O_2, N_2, water vapour in the troposphere). In 1979 James Lovelock (Atlas and Bartha, 1998) proposed a hypothesis named after the Greek earth goddess Gaia. *The earth acts as a super organism and that through the biochemical activities of its biota, its physicochemical properties are self regulated so that they are maintained in a favourable range for life*). These complex chemical reactions are mediated by microorganisms especially bacteria. Examples of these chemical reactions are the biogeochemical cycles (carbon, nitrogen, oxygen cycles etc). A shift in these equations either to the right or left of the equilibrium reaction as a result of man's interference sometimes in the form of environmental pollution upsets this balance. However, bacteria are largely responsible for maintaining this equilibrium (Odokuma and Okpokwasili, 1995). In every biogeochemical cycle microorganism play key roles. (Okpokwasili and Odokuma, 1996).

The role of bacteria in maintaining ecosystem integrity and balance is referred to in the bible "And … neither shall you eat any flesh that is torn of beasts in the field; you shall cast it to the dogs" (Exodus 22:31)(*Holy Bible* NIV 1984). This refers to abstaining from eating decomposing animal flesh (biodegradation, biogeochemical cycling of animal matter.)

ORIGIN OF LIFE

Phylogenetics (study of evolutionary relatedness among various groups of organisms through molecular sequencing data and morphological data matrices) has traced the origin of life to prokaryotes (eubacteria and archibacteria). A number hypotheses and theories have been advanced to explain the origin of life (e.g. chemical evolution and cellular evolution theories). Advances in biotechnology such as DNA finger printing, ribosomal RNA sequencing polymerase chain reactions and nucleic acid hybridization have shown that the first forms of life on earth were bacteria (Atlas and Bartha 1998).

Chemical Evolution Hypothesis/Theory

This is essentially the process by which increasingly complex elements, molecules and compounds developed from the simpler chemical elements that were created in the Big Bang. Recent astronomical observations have discovered that chemical evolution has even led to the synthesis of complex organic molecules in space, a discovery that could have serious implications on current theories of how life developed

1 The Earth and atmosphere formed.

2. The primodial seas formed

3. Complex molecules were synthesized

4. Polymers and self-replicating molecules very synthesized

5. Organic Molecules were concentrated and

isolated into protobionts.

6. Primitive heterotrophic prokaryotes formed.
7. Primitive autotrophic prokaryotes were formed

8.Oxygen and the ozone layer formed and abiotic chemical evolution ended.

9. Eukaryotes formed (endosymbiotic theory)

Cellular Evolution Theory

Life did not begin with one primordial cell. Instead, there were initially at least three simple types of loosely constructed cellular organizations. They swam in a pool of genes, evolving in a communal way that aided one another in bootstrapping into the three distinct types of cells by sharing their evolutionary inventions (Atlas and Bartha 1998).
The driving force in evolving cellular life on Earth, says Carl Woese, a microbiologist at the University of Illinois at Urbana-Champaign, has been horizontal gene transfer, in which the acquisition of alien cellular components, including genes and proteins, work to promote the evolution of recipient cellular entities.

Bacteria in Bible Creation story

Genesis1:11, 24 indicate that without microorganisms the creation/maintenance of stable populations of plants and animals (herbivores and subsequently flesh eating carnivores) would not have been sustained.

Genesis 1:11. “And God said, on the third day of creation let the earth bring forth grass, the herb yielding seed and the fruit tree after his kind” (*Holy Bible* NIV 1984)

The creation of plants, serving as food sources for mankind, land animals and birds had a high priority. Plants required both symbiotic and none symbiotic nitrogen fixing bacteria for the supply of plant nitrogen sources (ammonia, nitrates etc) for growth. Though the top soil of the freshly created earth may have been well fertilized with plant nitrogen sources, it is reasonable to expect that the newly created plants were endowed with nitrogen fixing symbionts on the third day of creation.

Genesis 1:24 “And God said let the earth bring forth the living creature after his kind, cattle (horses, goats, sheep and oxen), and creeping thing,” (*Holy Bible* NIV 1984) These cattle are ruminants i.e. obtain most of their required proteins from the digestion of microorganisms that grow in their rumen. Bacterial growth in the rumen becomes possible when the animal eats grass, rich in cellulose, indigestible by the cattle, but digestible by the resident rumen bacterial flora leading to the production of glucose which is used for growth by the cattle.

ENVIRONMENTAL POLLUTION MITIGATION

Pollution may be described as the undesirable change in the environment brought about by man’s activities. Environmental pollution is related to

environmental contamination. The difference is in the degree or concentration of these harmful substances. In the case of pollution the levels of these harmful sustenance's exceeds national and international limits (e.g. Federal Ministry of Environment, Department of Petroleum Resources World Health Organization). However contamination means presence of these substances above natural levels or biogenic levels, they may not necessarily exceed regulatory limits

Fig 2.0: Gas Flares

Fig 3.0: Crude oil pollution of a coastline

The adverse effects of environmental pollution may be mitigated by a number of options. The method employed must take into cognizance the following

- The laws of Nigeria
- Permissible limits for discharges and waste streams based on FMEnv/International standards.
- Best available technology for sustainable development
- Feasibility of application of the measure in Nigeria

- Concerns of stakeholders.

Available impact mitigation option includes the following (*Preparation and Implementation of Environmental Management Plan Shell Petroleum Development Company* 2004):

Avoidance: Avoiding projects or activities that could result in adverse impacts; avoiding certain types of resource or areas considered to be environmentally sensitive e.g. avoidance of forests reserves.

Preservation: Preventing any future actions that might adversely affect an environmental resource or attribute.

Minimization: Limiting the degree, extent, magnitude, or duration of adverse impacts.

Rehabilitation: Rectifying adverse impacts by repairing or enhancing affected resources.

Restoration: Rectifying adverse impacts by restoring the affected resource to an earlier (and probably more stable and productive) state.

Replacement: Compensating for the less of an environmental resource at one location with the creation of protection of that same type of resource at another location.

Improvement: This involves the enhancing of the capability of an existing resource with respect to its environmental functions

Augumentation: Increasing the area or size of an existing environmental resource

Development: Creating specific environmental resources in an area in which they are currently absent.

Diversification: Involves increasing the mixture or diversity of habitants, species, or other environmental resource in a circumscribed area.

Microorganisms in Pollution Mitigation

Biodegradation is a mitigation action employing microorganisms. It is the transformation of a substance through biochemical reactions or the action of microorganisms such as bacteria.

Biodegradation is a mitigation measure (remedial) measure employed in different forms bioremediation, biostimulation, bioaugumentation and biofermentation. It combines both rehabilitation and restoration mitigation options.
Biodegradation is a process by which microorganism transform or alter (through metabolic or enzymatic action) no structure of chemicals introduced into the environment (US Environmental Protection Agency, 2009) One of the objectives of biodegradation is to detoxify xenobiotics or other chemical compound s in the environment.

Oil spill countermeasures

Nigeria has an Oil Spill Contingency Plan (NOSCP) which has the objective of strengthening the nation's response to oil spill incidences in line with global best practices of protecting the environment through effective management of oil spills. The plan

Fig 4.0: Dredging and Sand filling

prepared in 2003 and was endorsed in 2005 by the Federal Ministry of Environment. It is implemented by the National Oil Spill Detection and Regulating Agency (NOSDRA) established in 2006. NOSDRA receives reports of oil spillages and coordinates oil spill responses throughout Nigeria. In the event of a spill NOSDRA may call upon Clean Nigeria Associates (CNA), an oil spill cooperative to assist in the response. Each operating oil company is

required by law to possess a contingency plan for the prevention, control and removal of spilled oil from its own facilities (1st tier). In addition CNA can be called upon by members when faced with spills beyond their capability of their own resources (usually above 2000 barrels 3rd tier). The NOSCP has a three tier response system:

Fig 5.0: A boom applied in a marine environment

Tier One

Operational type spills, less than or equal to 7 metric tonnes (50 barrels) or less, that may occur at or near a company's own facility, as a consequence of its own activities. An individual company would typically, and under Oil Spill Response Limited (OSRL) provide resources to respond to this size of spill.

Tier Two
A larger spill, greater than 7 metric tonnes (50 barrels) but less than 700 metric tonnes (5000 barrels), in the vicinity of a company's facility where resources from another company, industry and possible government response Agencies in the area can be called in, on a mutual aid basis. The company will participate in local co-operatives such as the Clean Nigeria Associates (CNA) where each member pools its Tier 1 resources and has access to any equipment which have been jointly procured for the co-operative.

Tier Three
The large spill, greater than 700 metric tonnes (5000 barrels), where substantial further resources will be required and support from a National (Tier 3) or International Co-operative Stockpile, like the Oil Spill Response Limited (OSRL), may be necessary. Such operation is subject to government control and direction. It is important to recognize that a spill which receives a Tier 3 response may be close to, or remote from company facilities.
Containment and recovery are the first response options in NOSCP. Dispersants are only permitted offshore in the NOSCP.

Mechanical containment or recovery: This is the primary line of defense against oil spills. It involves the use of containment equipment (booms, barriers and recovery equipment (skimmer) as well as natural and synthetic sorbent materials for the

capture and storage of spilled oil until it can be disposed of properly.

Physical methods: These methods are used to clean up shoreline, by wiping with sorbet materials, pressure washing raking and bulldozing.

Chemical and biological methods: These processes are used in conjunction with mechanical means for containing and cleaning up spills. Dispersing agents (Dispersants) and gelling agents (solidifiers – react with oil to form rubber-like solids which are removed from the water using nets, suction equipment, or skimmers).

Scare tactics: These methods are used to protect birds and animals by keeping them away from oil spill areas.

Fig6.0: An airplane applying dispersants on a crude oil polluted marine system

Application of Dispersants

The application of dispersants as an oil spill countermeasure in marine environments (offshore) is permitted in Nigeria by the NOSCP. However, the use of dispersants is not recommended onshore and in freshwater habitats especially in mangrove ecosystems in Nigeria because of their biodegradability, toxicity and habitat sensitivities.

Research contributions

Biodegradation of oil spill dispersants:

Dispersants contain surfactants and /solvent compounds that act to break petroleum oil into small droplets. In an oil spill, these droplets disperse into the water column where they are subjected to natural processes such as waves and currents that help to break them down further. The small droplet thus, formed exposes a greater surface of the petroleum oil to microbial degradation (Okpokwasili and Odokuma 1990, 1992) Microbial action is also responsible for the degradation and subsequent removal of both the dispersant and the dispersant oil mixture Odokuma and Ogbu 2002, Odokuma and Kindzeka, 2003, Odokuma and Williams 2010, 2012).

Okpokwasili and Odokuma (1990) observed that in hypersaline fresh water systems biodegradation of three oil spill dispersants used in the Nigerian petroleum industries (Corexit 9527, Surflo OW-1

and Prodesolv) and three industrial detergents (Sodium dodecylsulfonate, Teepol and TritonX-100 decreased with increase in salinity. They observed that in addition to the inability of microorganism to tolerate hypersaline conditions other factors that affected dispersant degradation in fresh water included water solubility, vapour pressure, polarity volatilization, and chemical composition of dispersants. Odokuma and Okpokwasili (1992) observed that these oil spill dispersants were more degradable than the industrial detergents (Teepol, Triton, X-100 and Sodium dodecylsulfonate). Both studies showed that biochemical and chemical oxygen demand (BOD and COD) of oil spill dispersants were so high such that application of these dispersants as an oil spill countermeasure increased organic carbon levels in receiving systems (marine environments). This showed the need for available heterotrophic microbial population that will ultimately degrade both petroleum oil and the dispersant

Biodegradation of drilling muds.

Petroleum oil is not the only hazardous material introduced into the environment as a result of petroleum upstream activities. Drilling muds employed during petroleum exploration to remove surface cuttings, can affect ecosystem negatively. Drilling muds are suspensions of solids (e.g. clays, barite, and small cuttings) in liquid emulsions with chemical additives to modify their properties (Ifeadi *et al* 1985). According to Muhelmann (1986) the chemical additives in drilling muds include bactericides, lubricants, detergents, dispersants,

defoamers, deflocculants, retarders, slurry extenders, viscosifiers, thinners and pH control additives. The individual components of the chemical additive in the mud may pose toxicity problems (Terrens *et al* 1998). Drilling muds are usually named according to their continuous phase; water, oil or gas and the type of chemical inhibited for certain desired performance characteristics. Nine distinct mud systems are defined; the first seven are water based. The eighth is oil-based. The ninth category is a specialized one in which air or gas is the basic circulating medium. In the Nigerian petroleum industry both water-based and oil-based mud systems are employed (Ifeadi *et al* 1985).

Research contributions

In Nigeria drilling muds and cuttings were formally discharged into fills and from here they overflow into nearby farms and rivers. These drilling muds if discharged untreated into the environment generally may have adverse effects on the ecosystem. Microbial degradation of drilling muds and cutting, have been investigated as a waste treatment option. Odokuma and Ikpe (2003) while investigating the role of composition on the degradability and toxicity of drilling muds observed that both water-based and oil-based drilling muds were biodegradable in brackish water environments. However, the water-based muds were more biodegradable than oil-based muds. The oil based muds were more toxic to *Nitrobacter* (bacteria) *Palaemonetes africanus* (brackish water crustacean) and *Melampus* sp (brackish water

snail). The water based muds were not toxic to these organisms. The authors concluded that the use of oil based muds should be discouraged during drilling operations based on their toxicity. Based on this study and similar ones the Petroleum industry in Nigerian has developed alternative treatment and disposal options instead of disposing them into the environment. These include the treatment in thermo-desorption Units (TDU) or the disposal into cutting re-injection wells.

Biodegradation of Leachates

Microbial degradation of organic compounds in many environments is severely limited by the availability of oxygen Lee and Levy (1991). In surface soil, air filled spaces in the soil facilitate diffusion of oxygen to heterotrophic bacteria while in deep soil oxygen levels are extremely low and may not keep up with the demand of heterotrophic decomposition process. The population of resident heterotrophic bacterial flora in subsurface soil is usually much smaller than in surface soil (Stanier *et al* 1982). Microorganisms in such subsurface environments degrade organic substances slowly when compared with the surface environment (Aelion and Bradley 1991).

Research contributions

In a landfill the leachate degradation at soil depth 6.5m and below is expected to be slow as a result of reduced oxygen levels. Leachates are produced as a result of the biological breakdown of organic wastes. The biodegradation process is influenced by the nature of the carbon source and the type of

bacteria active in the landfill material. Odokuma and Akpokodje (2004) investigated the extent of biodegradation in deep soil (6.5m deep) in two concentrations (high and low) of organic carbon source (olive oil) nitrogen source (ammonium sulphate) and sodium chloride. Their findings revealed that even in soil at 6.5m the extent of biodegradation of olive oil was not significantly different from surface soil. Thus though there is oxygen limitation the availability of limiting nutrients (nitrogen and phosphorus) will overcome this limitation and promote biodegradation at this depth. Landfills are not normally deeper than this so the ultimate degradation of wastes in this treatment facility is a function of the availability of heterotrophic microbial populations.

Biodegradation of Hair shampoos

Hair shampoos are often mixtures of several ingredients designed to satisfy a number of requirements (Jones *et al* 1987). The use of shampoos is for general cleaning and the removal of treatments from the hair dirt and skin debris from the hair. The composition of shampoos has changed over the years beginning with soap based products and now including synthetic surfactants. These synthetic surfactants consist of a long hydrophobic chain and a highly polar group that interacts slowly with the water (Swisher, 1987).Shampoos are typically discharged into the environment through sewage treatment infrastructure, or directly in situations where no treatment systems are available. Of all natural receiving systems water is the most severely

threatened (Arika *et al,* 1998). These shampoos may be biodegraded in these receiving systems.

Research contributions

Odokuma and Otokunefor (2003) while investigating biodegradation of hair shampoos in fresh brackish and marine waters of the Niger Delta made the following observations. In natural aquatic systems increased salinity may not necessary reduce the rate of biodegradation of an organic substance. Biodegradation is a function of the genetic make-up of the existing indigenous heterotrophic bacteria of the receiving system or the chemical composition of the shampoo. They also showed that continuous exposure of the resident heterotrophic population to the shampoo or other chemicals that are of similar chemical composition may promote rapid biodegradation of the shampoo. They finally observed that primary biodegradation and mineralization of the shampoos was greater in fresh and marine water than in brackish water.

Biodegradation of household insecticides

Insecticides are compounds containing both organic and inorganic moieties. They may be classified into different groups based on their chemical composition. These include organochlorines, organophosphates, organosulphates, carbarmates, formamidines, thiocyanates, organotines, denitrophenols synthetic pyrethyroids and antibiotics (Bohmont, 1990). Most of the household insecticides used in Nigeria

consist of a mixture of synthetic pyrethyroids and antibiotics.
Insecticides are used to increase crops yields by reducing pre and post harvest losses caused by pests.
However apart from their merits the various properties that promote their efficacy such as toxicity, solubility and chemical composition may also promote their persistence. Uncontrolled and indiscriminate use of insecticides may cause irreversible environmental damage.

Fig 7.0: Spraying of plants with insecticide

Research contributions
Odokuma and Omunakwe (2004) studied the biodegradability of four household insecticides in a tropical rainforest soil. The insecticides were pyrethrum (Blue Raid), propoxur (Baygon) tetramethrin 0.2% (Red Raid) and tetramethrin 0.3% (Mobil). Results showed that these insecticides are readily biodegradable in the

rainforest soil of the Niger Delta. Results also showed that these insecticides in their current formulations may serve as excellent sources of carbon and energy for indigenous heterotrophic microbial populations in the soil. The results finally showed that the insecticides may actually promote aspects of soil biogeochemical cycles in which the microorganism are involved.

Biodegradability of electrostatic photocopier toner.

Photocopiers, laser printers and other electronic duplicating devices have increasingly become a regular feature in offices and business centers in Nigeria.

Photocopiers are made to function by the simple application of a chemical substance called the Toner (NOHSC 1994). They are fine powders composed of plastic colorants and small quantities of functional additives (Espy, 1995).

In Nigeria the used toner products are re-used through the copiers a number of times and then discarded with the cartridges into the environment. This exposes the maintenance workers to inhalation of the toner dust particle. Some of the toner dust is left behind and discarded into the environment. The major component of any toner is either, styrene acrylic, styrene acrylate, styrene butadiene or polyester polymers and carbon black. These components may be toxic to indigenous microflora inhabiting receiving systems (terrestrial

and aquatic habitats). Some of these components may be mutagenic.

Research contributions

Odokuma and Okey (2005) while investigating the biodegradability of toner brands (Minolta and Sharp) showed a 74.7 to 85% total organic carbon removal after 28 days. The study also revealed that the unused toners were more readily degraded than re-used toners. The processing (heat e.t.c) in the photocopier may have modified the chemical composition of the toner, thereby reducing its biodegradability. This study suggests that toners should not be reused.

Biodegradability of GSM Recharge Cards

Since the first commercial GSM (Global System for Mobile Telecommunication) services were provided in mid 1991, this novel technology has received great and enthusiastic patronage in Nigeria. In Nigeria the advent of GSM has brought in its wake a communication revolution (Odokuma and Nwaokeleme 2005: Odokuma and Okara 2005) Recharge cards are components of GSM technology. The network operators for the purpose of prepaid mobile telephone services provide them as vouchers. Some of these recharge cards are composite of plastics with compressed paper while others do not contain any plastics.

Plastics cover a wide range of diverse structures including formulations, composite and copolymers. Thus biodegradation of a plastic is a function of the chemical composition.

Paper consists mainly of cellulose. Its biodegradability depends upon suitable environmental conditions for colonization of microorganisms (Alexander 1994).
In the Niger Delta, recharge cards are indiscriminately discarded on land and in creeks and rivers (Odokuma and Nwaokeleme 2005). They are found in filthy litters causing sanitary as well as aesthetic problems. Such discarded cards increasingly constitute a significant proportion of urban solid waste (Odokuma and Okara, 2005). Biodegradation is an efficient and cost effective way of removing them from the environment.

Research contributions
Odokuma and Nwaokeleme (2005) showed that in aquatic systems recharge cards were non toxic to heterotrophic microbial flora of fresh, brackish and marine aquatic systems of the Niger Delta. They also showed that the recharge cards used in Nigeria were all biodegradable. However biodegradation was greatest in freshwater and least in marine water.

Odokuma and Okara (2005) working with similar substrates in the tropical terrestrial systems obtained similar results. They observed that the recharge cards were not toxic and were readily degradable in rainforest and mangrove soils of the Niger Delta.

BIOREMEDIATION

This is the use of microorganisms (bacteria and fungi) metabolic processes (biodegradation, bioaccumulation, biofermentation, bioabsorption, bioadsorption etc) to remove pollutants from the environment.

The advantages of bioremediation option include inexpensive equipment, environmentally friendly nature of the process and simplicity (Odokuma and Dickson 2003). The disadvantages of the process include its relative slow speed in achieving results and its requirement of relative low concentrations of the pollutant for removal. Bioremediation is usually employed with other physical and chemical remediation options. These options reduce the concentration of the pollutant to levels that are non-toxic to the biodegrading bacteria. These organisms then ultimately degrade the pollutants into environmentally recyclable components.

Bioremediation technologies may be classified as in-situ or ex-situ. In-situ bioremediation involves treating the contaminated material at the site, while ex-situ involves the removal of the contaminated material to be treated elsewhere. Some examples of bioremediation technologies include bioventing, bioleaching, land farming, biofermentation, composting, bioaugumentation, biostimulation, Phytoremediation (Phytoextraction and Rhizofiltration) and Microbial mats.

Bioremediation can occur on its own (natural attenuation or intrinsic bioremediation) or can be

initiated or promoted (bioaugumentation, biostimulation, biofermentation, bioventing and composting). Biostimulation involves the addition of fertilizers to increase the bioavailability within the medium while bioaugumentation involves the addition of external microbial populations (indigenous or exogenous) to waste (Lee and Levy 1991). Sometimes these microbial populations are genetically engineered). Land farming is a bioremediation treatment process that is performed in the upper soil zone or in biotreatment cells.

Composting involves aerobic degradation of solid domestic organic waste into a form that can be used as a form of soil amendment. Microbial mats (algal mats, biomats) are layers (biofilms) of cyanobacteria on surfaces (rocks, sand, sediment e.t.c.). Some mats contain other heterotrophic bacteria that derive their nutrition from the autotrophic bacteria (cyanobacteria).These mats can be grown in the laboratory or in the field and be employed in the treatment of effluents or bioremediation of polluted aquatic systems.

Fig 8.0: Compost

Contaminated soils, sediments, or sludges are incorporated into the soil surface and periodically turned over (tilled) to aerate the mixture. Bioventing uses microorganisms to biodegrade organic constituents adsorbed on soils in the unsaturated (vadose) zone (portion of soil that extends from the top of the ground surface to the water table) by inducing air or oxygen flow into the unsaturated zone and, if necessary, by adding nutrients.

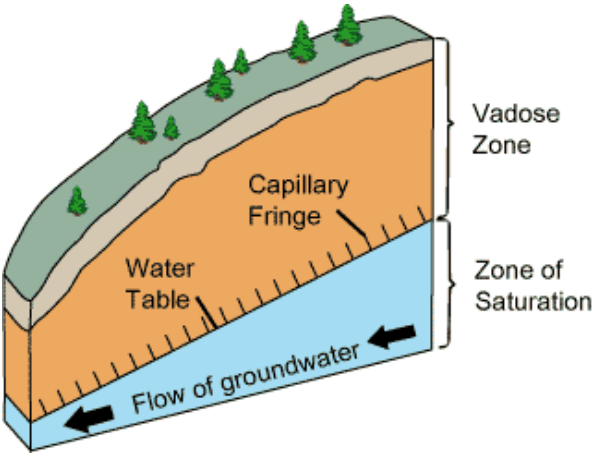


Fig9.0: Vadose Zone

Biofermentation involves the growth of bacteria or fungi in suitable substrates in large tanks called bioreactors.

Phytoextraction is a sub process of phytoremediation in which plants remove dangerous elements or compounds from soil
Rhizofiltration (Phytofiltration) which is similar to phytoextraction is a form of bioremediation that involves filtering water through a mass of roots to remove toxic substances. Contaminants are either adsorbed onto the root surface or absorbed by the plant roots. It is used in the remediation of contaminated ground water. Bioleaching is the extraction of specific metals from their ores through the use of living organisms such as bacteria.

Research contributions

Bioremediation of Crude oil Polluted Rainforest soil.

Odokuma and Dickson (2003) examined a combination of options for the clean-up of a crude oil polluted tropical rainforest soil for a period of nine weeks. The options included biostimulation with agricultural fertilizers and some physical clean-up options. The study showed that biostimulation with tilling (nutrient enhanced in-situ bioremediation) and or the combination of biostimulation and bioaugumentation with indigenous hydrocarbon utilizing bacteria would be effective in the remediation of crude oil polluted tropical soils.

Odokuma and Ibor (2003a) showed that bioremediation of crude oil polluted tropical rainforest soils through the addition of nutrient supplementation (biostimulation) is a suitable option to accelerate the process of natural clean-up of a soil. They observed that the addition of inorganic fertilizer NPK 15:15:15 proved to be better option than the addition of any of the other options, urea, $NaNO_3$, K_2HPO_4, humus and single superphosphate. Single superphosphate was the least suited for the soil studied.

Odokuma and Ibor (2003b) employed the use of nitrogen fixing bacteria to enhance bioremediation of a crude oil polluted soil. They showed that the extent of bioremediation was greatest with nitrogen fixers. Nitrogen is a limiting nutrient for the process of biodegradation. The presence or absence

of nitrogen affects the rate of biodegradation, because nitrogen is an essential nutrient for the metabolic activities of microorganisms. They observed that the highest percentage loss of crude oil (84%) was recorded in soil which contained seeds of *Phaseolis vulgaris* (white beans) and *Bacillus polymyxa.* Soils containing *Anacystis (Chroococcus*) sp with *Azotobacter* and *Bacillus polymyxa* recorded 80% loss of crude oil. The soil containing the NPK 15:15:15 showed a crude oil loss of 64%. The soil containing NPK 15:15:15 with seeds of *Phaseolis vulgaris* a 64% loss while the soil containing NPK 15:15:15 with *Anacystis* showed a 72% loss.

Bioremediation of Crude oil Polluted mangrove environments

Bioremediation of mangroves habitats is difficult because of their sensitive biota and tidal influence that inundate these environments.

When a spill occurs in these habitats unless it is contained quickly the biota can be damaged quickly. Also the near anaerobic conditions that prevail in mangrove soils will reduce biodegradation of the oils slick which is largely facilitated by aerobic organism. Also physical processes such as tilling which would have assisted aeration of the soils are difficult because of the stilt roots of the mangrove plants. These and some other factors make remediation of such environments an uphill task.

Odokuma and Dickson (2003b) investigated a number of options for the bioremediation of a medium spill impacted tidal plain dominated by mangrove plants (*Rhizophora, Laguncularia* and *Avicenia*) in the Niger Delta for 20 weeks. Four options were employed; Option A (biostimulation, bioaugumentation and tilling) Option B (bioaugumentation and tilling option D (biostimulation and tilling; Option C (control- no treatment) They observed that Option A and D recorded the highest hydrocarbon losses of 84% and 82% respectively, while Option B (72%) and Option C (65%). Thus the combination of bioaugumentation, biostimulation and careful tilling may be employed to bioremediate polluted mangrove soils.

Bioremediation Pesticide Polluted soils

Odokuma and Akubuenyi (2008) studied the effect of three agricultural pesticides; k-othrin (deltamethrin), dichlorvos (2, 2 dichlorovinyl dimethyl phosphate) and carbofuran (2, 2-dihydro-22-dimethylbenzofuran-7-y 1methylcarbamate) on the degradation of medium spill concentrations of Bonny light crude oil in the Niger Delta. The study revealed that the application of pesticide to tropical soil impacted with medium spill levels of Bonny light recorded higher losses in treatments involving pesticides/crude oil mixtures when compared with pesticide alone options suggesting possible enhancement of crude oil degradation. Hydrocarbon loss was greater in the option containing soil with crude oil alone than in other two options, suggesting toxic effects of pesticides

on indigenous organisms. Percentage mineralization in treatment options were however, greater in pesticide alone options than in pesticide/crude oil mixtures suggesting combined toxic effect of both constituents on resident soil microflora and the degradability of these pesticides.

BIOACCUMULATION

This is the accumulation of substances/chemicals in the tissue of living organisms. It involves both bioconcentration and biomagnifications. Bioconcentration is the uptake of chemicals directly from water without an intermediate organism while biomagnifications is the occurrence of chemicals within the tissue of organisms as we progress through successive trophic levels. Biosorption is the attachment of chemicals to the surface of organisms.

There is a continuous influx of heavy metals in to the biosphere from both natural and anthropogenic sources (Perelomov and Prinsky, 2003). Crude oil is also a source of these metals. In aquatic and terrestrial ecosystems their bioavailability depends on their chemical forms. These heavy metals are known to cause severe damage to aquatic and terrestrial life (Odiete, 1999, Odokuma and Emedolu 2005). A specific problem associated with metals in the environment is their accumulation in the food chain and persistence in the environment (Malekzadeh *et al,* 1996). Microorganism, uptake metal either actively (bioaccumulation) and/or passively (biosorption) (Shummate and Strandberg 1995). Thus the use of microorganisms for the

recovery of metals from waste stream has received growing attention.

Alternative metal removal and /recovery methods include physical and chemical methods such as chemical precipitation, chemical oxidation or reduction, electrochemical treatment, evaporative recovery, filtration, ion exchange and membrane technologies (Malekzadeh *et al,* 1996). However, these physical and chemical methods have limitations when the heavy metal ions are in solution containing in the order of 1-100mg dissolved heavy metal ions may be ineffective or expensive.

Metal removal and recovery methods based on metal –sequestering properties of certain natural materials of biological origin have addressed this limitation. Certain types of microbial biomass can retain relatively high quantities of metal ions by passive sorption and/or complexation, this is known as biosorption (Volesky 1995, Ahalya *et al.,* 2003). Ion exchange and complexation are the main mechanisms for bioconcentration (Volesky 1995, Ahalya *et al* 2003). Commonly used procedures for removing metals from aqueous streams such as reverse osmosis, electrodialysis, ultrafiltration, ion exchange, chemical and precipitation have a number of disadvantages which include incomplete metal removal, high reagent and energy requirements, generation of toxic sludge or other waste products that require careful disposal (Ahalya, *et al* 2003, Arief *et al* 2008).

However, methods such as bioaccumulation (bioconcentration and biosorption) offer a number of advantages. These include low cost, high efficiency, minimization of chemical and biological sludge, no additional nutritional requirements, and regeneration of biosorbents and possibility of metal recovery (Odokuma and Akponah 2010). Bioaccumulation makes use of three processes biodegradation, bioaccumulation and biosorption (Odokuma and Akponah 2010). Bioaccumulation involves bioconcentration and biomagnification.

Bioaccumulation of heavy metals may therefore provide an attractive alternative to physical and chemical methods. Bioaccumulation is a normal and essential process for the growth and survival of organisms. All organisms tend to accumulate many vital nutrients such as vitamins, trace elements, fats, amino acids etc. (Ford and Mitchel, 1992) bioaccumulation is also important because even very low concentrations of chemicals in the environment can find their way into the organisms in high enough dosages to cause death or adverse effect on behaviour, reproductive or disease resistance and this endangering these organisms. A number of factors may affect the rate at which bacterial cells accumulate heavy metals. These include temperature biomass, duration of exposure, binding capacity of metal / chemical, species of organism and the presence of other contaminants.

Research contributions

Odokuma and Akponah (2009) investigated the effect of culture age and biomass concentration of *Bacillus, Pseudomonas* sp and *Aeromonas* sp on their capabilities of bioconcentrating various heavy metals associated with crude oil (Fe, Zn, Cu, Cd, Pb and N). The study revealed that the culture age (of 24-48h for *Bacillus* and 72h for both *Pseudomonas* and *Aeromonas)* and very high concentrations of biomass had significant influences on improving the bioconcentration capabilities of these isolates under the test conditions. Thus in a waste stream or aquatic system containing non toxic concentrations of heavy metals (Fe, Zn, Cu, Pb and N,) high biomass concentrations (dependent on the heavy metal) and exposure of 24h culture of *Bacillus* or a 72h cultures of *Aeromonas,* or *Pseudomonas* would promote bioaccumulation these heavy metals.

Odokuma and Akponah (2012) investigated the effect of pH on the uptake of heavy metals (Fe, Zn, Cd, Cu N, and Pb) on these organisms. Results showed that low pH levels (5.5 - 7.0) increased their bioaccumulation efficiencies. Maximum uptake of heavy metals occurred with pH range of 5.5 – 7.0.
The effect of heavy metal concentration and contact time (exposure period), on uptake of these metals by these organisms were investigated by Odokuma and Akponah (2010). The study showed that heavy metal concentrations of between 10-100mg/L and exposure periods of between 4-12h depending on the metal and the test organism rapidly promoted accumulation in heavy metal polluted sites.

Odokuma and Akponah (2010) also investigated the effect of nutrient supplements (NPK 15:15:15 fertilizer and poultry litter) on the biodegradation of crude oil and metal uptake by these organisms. Results showed that nutrient supplementation with NPK 15:15:15 and poultry litter promoted both biodegradation of crude oil and heavy metal uptake in both crude oil impacted fresh and brackish water test systems. Thus a combination of bioaugumentation with indigenous species of *Bacillus a*nd *Pseudomonas* and biostimulation with NPK 15:15:15 or poultry litter may be employed to bioremediate (biodegrade and bioconcentrate) crude oil impacted fresh and brackish water systems of the Niger Delta.

In the *Environmental Guidelines and Standards for the Petroleum Industry in Nigeria* (EGASPIN) (2002) protocol for carrying out bioaccumulation studies a key trophic level is omitted. This trophic level represents the primary producers and for any food chain to be complete it must contain organisms in this niche. For instance the EGASPIN (2002) protocol for bioaccumulation tests involves the use of the following organisms, crustaceans, molluscs and fishes (all these are consumers) leaving out autotrophic organisms. We have suggested/developed a protocol beginning with primary producers such as unicellular algae/cyanobacteria/chemoautotrophic bacteria (e.g. *Nitrobacter)*. This procedure is definitely more representative of natural aquatic systems.

ENVRONMENTAL MONITORING (BIOMONITORING)

Environmental monitoring is an efficient means of measuring the impacts of both humans and natural forces on the ecosystem of an area, which may be induced by sudden discrete events (e.g. oil and chemical spills, emissions) or long term climatic induced changes (Odokuma *et al* 2008).

It is a statutory requirement, a license to operate (LTO) condition as well as an external certification requirement (EGASPIN 2002, *Federal Ministry of Environment National Guidelines and Standards for Water Quality in Nigeria* 1991). It is a means of monitoring the efficiency of the engineering process ensuring minimal impact on the environment and thus improving the operator's social performance.

In line with existing regulatory and statutory requirements, environmental monitoring includes but not limited to:

- Ground water monitoring
- Biological monitoring
- Gaseous point source emission
- Rain water and storm water monitoring
- Effluent monitoring
- Recipient environmental monitoring
- Naturally occurring radioactive materials monitoring

A number of tools exist for environmental monitoring these include web based geographic information system image processing tools,

microbiotest tools and quantitative and qualitative analytical tools (Odokuma *et al* 2008)

Quantitative and qualitative analytical tools employ Environmental Quality Guidelines (EQG) to determine environmental quality Environment Quality Guidelines are nationally approved science based indicators of environmental quality. They are recommended numerical or narrative limits for a variety of substances and Environmental Quality Parameters (EQP), which if exceeded; may impair the health of the ecosystem.

The guidelines may be used as recognized instruments to support regulatory and non-regulatory efforts on toxic substances pollution management at the state, national and international level. They provide nationally endorsed science based bench marks for assessing the risk of priority substances to aquatic and terrestrial organisms; targets towards which environmental control measures/pollution prevention efforts can be directed; and performance indicators to help evaluate, track and / or improve upon the effectiveness of existing or proposed management measures.

Environmental Quality Parameters may be divided into physicochemical and biological parameters; (Odokuma and Okpokwasili 1993a 1993b Odokuma and Okpokwasili 1997) Physical chemical parameters may include pH, temperature, conductivity, Total Suspended Solids (TSS), sulphates, nitrates etc. The biological components

of EQPs include microbiological parameters (total heterotrophic bacteria, total fungi, hydrocarbon utilizing bacteria e.t.c)

The biological components of EQPs are also called biological indicators (bioindicators). Biological indicators (bioindicators) these are species used to monitor the health of an environment or ecosystem. They are biological species or group of species whose function, population or status can be used to determine ecosystem or environmental integrity. Bioindicators may either be microorganisms or macrooganisms. Examples of microbiological indicators include Total Heterotrophic bacterial total fungi, Hydrocarbon utilizing/degrading bacteria, hydrocarbon utilizing/ degrading fungi, total coliforms, fecal coliforms pesticide utilizing / degrading bacteria/fungi, surfactant utilizing / degrading bacteria / fungi, Heavy metal utilizing/degrading bacteria/fungi etc.

Bioindicators can serve as biomonitors. Biological monitors (Biomonitors) are defined as organisms that provide qualitative (and to some extent quantitative) information on the quality of the environment around it. Therefore a good biomonitor will indicate the presence of the pollutant and also attempt to provide additional information about the amount and intensity of the exposure.

A bioindicator is an organism or biological response that reveals the presence of the pollutants by the occurrence of typical systems or measurable responses and is therefore qualitative.

While physicochemical indicators / monitors provide quantitative estimation of the pollutant in the environment biomonitors provide qualitative information on the pollutant. It determines the physiological, chemical and behavioural effect of the pollutant on organism within the receiving systems.

Trend Analyses

Trend analyses involves determining the trend of an EQP. Environmental monitoring assists in determining trend analysis. Trend analyses aims to advance the science of ecological monitoring and ecological risk assessment, assist corporate and national monitoring by providing a data bank of environmental quality parameters within the area of the organizations operation (Odokuma *et al* 2008). Trend analyses improve the scientific understanding of ecosystem integrity and dynamics. It also demonstrates the organization commitment to the environment.

The objectives of trend analyses include monitoring the following:

- The impact of operational activities on receiving systems.
- The integrity of the receiving system (ascertain whether EQPs were within regulatory limits)
- Spatial variation (statistically significant) in the concentrations of EQPs between locations.
- Provide a data bank of EQPs that could be readily accessible to end users

- Track changes in the ecosystem of the receiving system, thereby serving as an early warning indicators of pollution within the system
- Evaluate and improve on existing mitigative actions to remedy potential impacts from xenobiotic and anthropogenic sources.

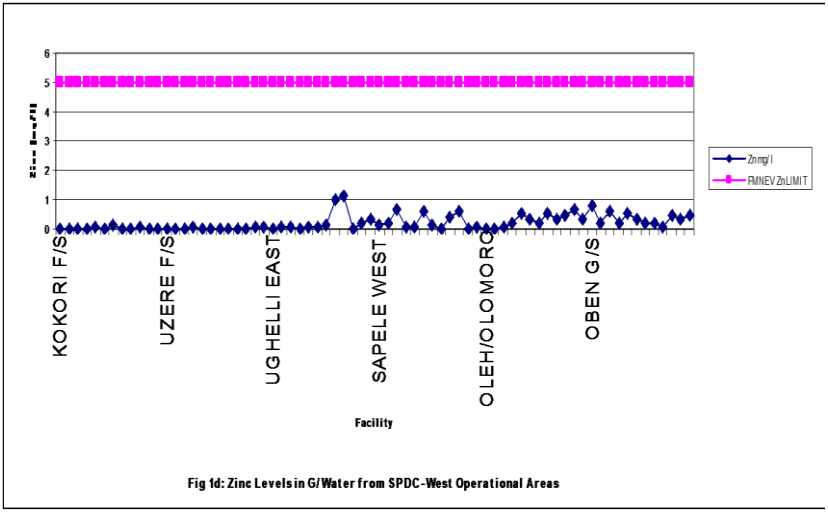


Fig 10.0: Graph showing zinc levels in groundwater

Research contributions

Odokuma *et al* (2008) demonstrated the trend analyses of some ground water physicochemical parameters in Shell Petroleum Development Company (SPDC) operations in the Western Division Nigeria. (gas plants, gas compressor stations and flow station). The study revealed that trend analyses of identified EQPs in groundwater can enable monitoring the groundwater ecosystem integrity, determination of impacts of operations

and monitor spatial variation and dynamics of these parameters.

Odokuma and Okpokwasili (1993) observed seasonal changes in the microbial communities of the New Calabar River water. They observed high densities of hydrocarbon –utilizing microbial populations in the rainy season compared to the dry season. However, hydrocarbonoclastic mould, yeast and actinomycetes populations showed no seasonal variation. A higher percentage of hydrocarbonclastic organisms were obtained in effluent discharge sites for all microbes except cyanobacteria probably revealing the sensitivity of cyanobacteria to these effluents. Odokuma and Okpokwasili (1993) observed high concentrations of some EQPs (sulphite, nitrate, phosphate and alkalinity) in the rainy season while others (dissolved oxygen, pH, sulfide sulfate, ammonia and nitrite) showed no seasonal variation.

Odokuma and Okpokwasili (1997) observed high organic EQPs such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and total hydrocarbons in the rainy season while anionic surfactants levels were not affected by season.
Odokuma and Ijeomah (2002) observed that the percentage of heavy metal resistant bacteria in the New Calabar river water was greater in the dry season then in the rainy season, the converse was the case for total aerobic heterotrophic bacterial population. Odokuma and Isirima (2007) while investigating the presence and type of cyanotoxins in some aquatic environments in the Niger Delta

observed that all the aquatic systems were found to contain both cyanobacteria and harmful cyanotoxins (toxins produces by Cyanobacteria) however, in harmless concentrations. Thus the surface waters may pose a potential health risk with regards cyanotoxin poisoning. Also cyanobacterial cyanotoxin detection should be included in water analyses protocol in Nigeria.

Adoki and Odokuma (2007) while investigating the utilization of three petroleum hydrocarbons, (Mobil SAE 40 Engine Oil, Diesel and Bonny light crude oil by four bioluminescent bacteria (*Vibrio harveyi*, *V. fisheri, Photobacterium leiognathi a*nd *P phosphoreum*) isolated from Bonny Estuary in the Niger Delta made the following observations. Bioluminescent bacteria were widely distributed in the Bonny estuary and these organisms were capable of utilizing the petroleum hydrocarbons. The study also revealed that increasing phosphate levels in phosphate depleted marine waters could encourage the growth of these organism and therefore serve as a potential tool for the remediation of petroleum polluted marine systems.

ECOTOXICOLOGY

This is the study of the effects of toxic chemicals on biological organisms, especially at the population, community, ecosystem level.

Ecotoxicology is a multidisciplinary field, which integrates toxicology and ecology. The ultimate goal is to be able to predict the effects of pollution so that the most efficient and effective action to

prevent or remediate any detrimental effect can be identified. It differs from environmental toxicology in that it integrates the effects of stressors across all levels of biological organization from the molecular to whole communities and ecosystems, whereas environmental toxicology focuses upon effects at the level of the individual, organ or tissue: Many toxicity tests are accomplished by using microorganisms as test organisms. Such bioassays must provide rapid and reliable data so they can be extrapolated to inter human risk of exposure as well as trigger adequate waste management.

These tests are based on the inhibition of some microbial vital function. Examples include microtox tests, AMES Salmonella assay, SOS chromotest, MET PAD, algal bioassay, and carbon dioxide production. Others include the monitoring of internal pools of DNA and ATP.
These techniques have rapidity, simplicity and cost effectiveness as notable advantages over physicochemical techniques.

Okpokwasili and Odokuma have popularized the inhibition of nitrite and *Nitrosomonas* respectively as one of these tools.

Research contributions
Odokuma and Ogbu (2002) while investigating the tolerance of two bacteria *Bacillus* and *Escherichia* isolated from brackish water and two crustaceans – *Desmocaris trispinosa* (freshwater crustacean) and *Palaemonetes africanus* (brackish water crustacean) to three dispersants (Coldcrew, Dispolene 365, and All clean 100) and a domestic

detergent Teepol showed that the bacteria *Bacillus* and *Escherichia* were more tolerant to the dispersants and detergent than the crustaceans. Results also showed that the observation that a test chemical is toxic to one group of organism's e.g. crustaceans would not necessarily imply that other organisms could be affected to the same extent. It would be necessary to carry out such tests using organisms representing different ecological niches in a food chain in the recipient habitat.

Odokuma and Ikpe (2003) investigated the role of composition in the degradability and toxicity of four drilling muds, Petrofree Invermul (Oil-based) KCL-polymer and Prehydrated Gel (water-based) to *Nitrobacter* (bacteria), *Palaemonetes africanus* and *Melampus* sp (brackish water snail. Results showed that oil-based muds were more toxic the organism (bacteria, crustacean and molluscs) than water based muds. The water based muds were non-toxic to these organisms.
Okpokwasili and Odokuma (1996a) observed that drilling chemicals (Carbotrol) A9, Carbomul sea, Carbotec sea, Carbovis, Carbotec HW, Huile Clean and Chaux lime) inhibited nitrite utilization by *Nitrobacter* isolated from the New Calabar River water.

Odokuma and Kindzeka (2003) observed that oil spill dispersants were toxic to *Nitrobacter, Desmocaris trispinosa* and *Metylis edulish*. The effect of four hydrocarbon fuels (Jet fuel, kerosene, gasoline and diesel) on the nitrite utilization and

logarithmic rate growth of *Nitrobacter* was investigated by Okpokwasili and Odokuma (1996b). The results showed that *Nitrobacter* sensitivity to hydrocarbon fuels decreased in the order kerosene 7 Jet fuel = gasoline > diesel.

Okpokwasili and Odokuma (1993) while investigating the tolerance of *Nitrobacter* to toxicity of some Nigerian crude oil types (Bonny medium, Bonny light, Brass crude, Qua Iboe, UQCC and Trans National Petroleum) observed that the crude oil types inhibited population and nitrite utilization by the organism.

The effects of oil spill dispersants (Corexit 9527, Prodesolv and Surflo OW-1) and domestic detergents (Flex, Apollo, Rainbow, Spencer and Teepol) on nitrite utilization and percent log survival of *Nitrobacter* were investigated by Okpokwasili and Odokuma (1993). They observed that oil spill dispersants and domestic detergents inhibited nitrification and the growth rate of the organism.

Odokuma and Osuagwu (2004) while investigating the effect of some locally used pesticides (Lindane, Dieldrin, Actellic dust 2% Malathion Benomyl and Methomyl) on chimolithotrophic soil bacteria (*Nitrobacter, Nitrosomonas* and *Thiobacillus thioparus*) showed that the chemolithotrophic bacteria were tolerant to organophosphate pesticides (Actellic dust 2% and Malathion) but were very sensitive to organochlorine (Lindane and Dieldrin) and carbamate pesticides (Benomyl and Methomyl).

Odokuma and Oliwe (2003) showed that toxicity of benzene and substituted benzene derivatives (hydroxyl benzene, chlorobenzene, methyl benzene and dimethyl benzene to four chemolithotrophic bacteria (*Nitrosomonas Nitrobacter, Thiobacillus* and *Leptothrix* isolated from the New Calabar river water generally decreased in the order hydroxybenzene (Phenol) > chlorobenzene > benzene dimethyl benzene (xylene) > methyl benzene (toluene). These results showed that toxicity was a function of nature of substitution, degree of substitution and the organisms sensitivity to the chemicals. Sensitivity of the organisms to the benzene derivatives decreased in the order *Nitrosomonas* > *Leptothrix* > *Thiobacillus* > *Nitrobacter.*

Odokuma and Ijeomah (2003) investigated the tolerance to salts of four heavy metals (Cu, Cd, Pd and Zn) to mixed culture of four heavy metal resistant bacteria (*Bacillus Proteus, Alcaligenes* and *Arthrobacter*) isolated from the New Calabar River water. They observed that $ZnSO_4$. $7H_2O$ was the most toxic to these organisms while $CuCL_2$ $7H_2O$, $CdCL_2.6H_2O$ and Pb_3O_4 displayed similar levels of toxicities. They attributed toxicity of metal salts to solubility of the salt in water and its concentration.
Odokuma and Okpokwasili (2003) showed that the constitutive intracellular enzyme, nitritase produced by *Nitrobacter* was the most sensitive to the weathered Nigerian crude oils while two extracellular inducible enzyme tryptophanase produced *Escherichia coli* and α-glucosidase produced by *Bacillus* were less sensitive to the

weathered oils, though they were more sensitive than the intracellular inducible enzyme β-galactosidase produced by *E coli.*

The authors recommend inhibition of bacterial enzymes syntheses as a useful, cheap, simple and rapid ecotoxicity assay for monitoring pollution in the Nigerian environment.

MICROBIALLY INFLUENCED CORROSION (BIOCORROSION)

Corrosion or microbial influenced corrosion (MIC) refers to the influence of microorganisms on the kinetics of corrosion processes of metals caused by microorganisms adhering to the interfaces (usually called biofilms). A prerequisite for MIC is the presence of microorganisms.

Corrosion can be defined as the deterioration of a material by reaction to its environment corrosion occurs because of the natural tendency of most metals to return to their natural state e.g. iron in the presence of moist air will revert to its natural state, iron oxide. During corrosion the metal is oxidized.

Microbial corrosion (biocorrosion):

Biocorrosion occurs when complex microbial consortia interact with metallic surfaces through the establishment of multi species biofilms. Microbial corrosion is difficult to separate from purely electrochemical corrosion. Biocorrosion mechanisms may either be direct or indirect. Direct mechanisms occur where the organism is directly utilizing the metal or metabolizing a component of

the electrochemical process, such as hydrogen produced at the cathode. Indirect mechanisms involve bacteria or fungi setting up concentration or differential aeration cells on metallic surfaces or the production of acidic metabolic products, both of which can lead to corrosion (Allsopp and Seal (1986). Biofilms mediate interactions between metal surfaces and liquid environment, leading to major modifications of the metal-solution interface by drastically changing the type and concentrations of ions, pH, and oxygen levels. Biocorrosion of steel materials in gaining tremendous importance in the petroleum sector of Nigeria's economy. It has been associated with the rupture/failure of pipelines used in transporting petroleum and its products from oil and gas fields, flow stations, tank farms, depts. and terminals in Nigeria.

Unfortunately most of this corrosion has been reported as chemical corrosion or physicochemical corrosion. This is because of the thinking in the Nigerian petroleum industry that corrosion is mainly physicochemically induced. There is also the growing misconception that pipeline failure is as a result of sabotage. Microbial corrosion could lead to pipeline rupture.

Biocorrosion is microbially mediated. Bacteria such as sulphate reducing bacteria, Iron oxidizing bacteria and sulphur oxidizing bacteria have been implicated in anaerobic and aerobic biocorrosion respectively.

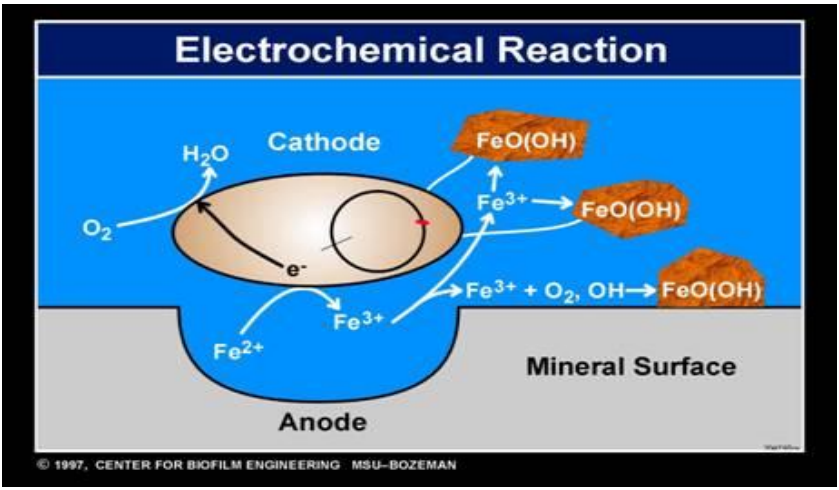
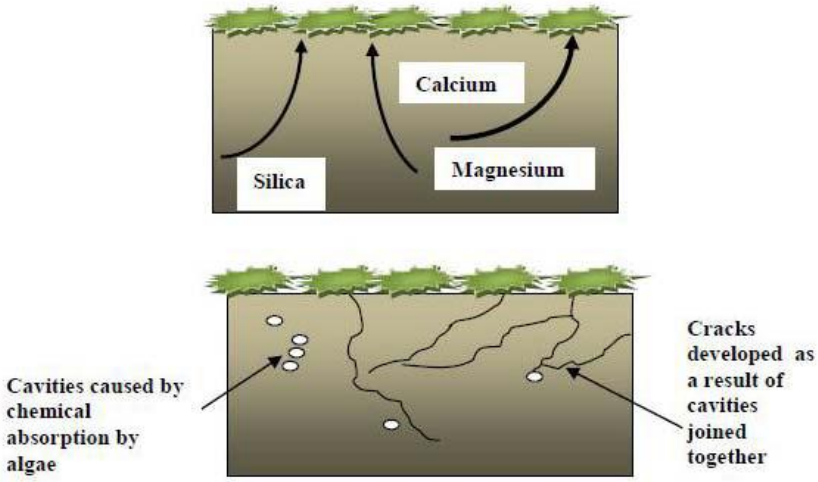


Fig 11.0: Electrochemical corrosion :(Reza *et al* 2009)



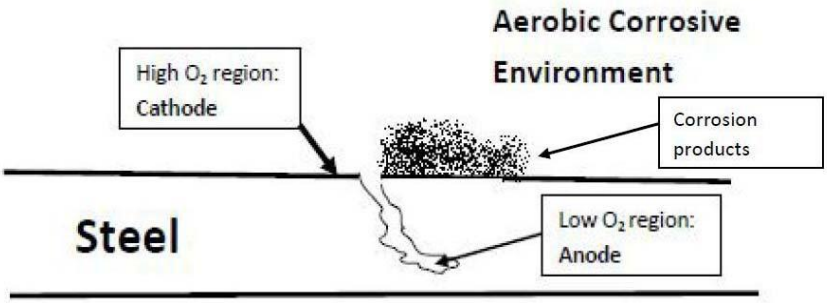


Fig.12.0: Biocorrosion by algae (Reza *et al* 2009)

Research contributions

Odokuma and Ugboma (2012a) while investigating microbial corrosion of stainless, mild and carbon steel materials used in construction of pipelines used in the petroleum industry in Nigeria made the following observations; carbon steel had a higher biocorrosion rate than mild steel in the fresh water habitat. Stainless steel had the least corrosion rate. They also observed that the biocorrosion rates were higher in the dry season than in the rainy season. They recommended the incorporation of stainless steel in the current composition of steel used for pipelines in fresh water environments as against the use of carbon steel by some operators in the oil and gas industry in Nigeria. Lastly they suggested that the frequency of integrity checks should be increased especially during the dry season. Similar observations were also made by Odokuma and Ugboma (2012) while investigating microbially induced corrosion of steel in brackish water habitats of the Niger Delta.

BIOMASS ENERGY

Traditional source of energy such as combustion of plants (wood) could lead to deforestation. Plant matter especially trees serve as a CO_2 sinks. Removing this sink and creating a CO_2 source through combustion of these plants contributes to global warming. The increased CO_2 levels as a result of removal of the sink (deforestation) and creation of a source (combustion) absorbs more radiation from the sun with consequent increase global average temperatures.

Fig. 13.0: Uncontrolled Logging

Fossil fuels such as Petroleum oil based fuels (Petrol, Kerosene, and Diesel) and Coal are some of the major sources of energy in the world. However, their combustion has been associated with increasing levels of green house gases (CO_2 and CH_4) emissions. Thereby contributing to enhanced

green house effect and consequently increased global warming.

This increased, global warming has been responsible for human induced (artificial) climate change.

Climate change may either be artificial or as a result of natural causes. Increases in global temperatures as a result of volcanic eruptions, meteor collision on earth increased sizes of solar flares (increasing size of the sun) and the increased shorter distance between the sun and the earth have one time giving rise to natural global warming and may still be contributing to the process. Fossil fuels, such as coal and petroleum based fuels or their sources (crude oil and natural gas) are classified as non- renewable forms energy. That is energy from sources that cannot be regrown/ replenished. Fossil fuel sources took millions of years to be formed. Even with the following trend, of aforestation and reforestation programmes may not be able to cope with the current rate of deforestation. However, renewable forms of energy such as hydroelectric, wave, wind, nuclear, solar, and biomass energy have sources that can be regrown/ replenished and are gaining increasing importance. Hydroelectric, wind, solar, waves and biomass energy are regarded as clean energy sources. They are regarded as clean energy sources because gaseous emissions such as H_2S, SO_2, NO_2, CH_4, CO_2 and CO are not produced or if produced as in the case of CH_4 during biogas production does not add to the global warming picture.

The Government of Nigeria is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) aimed at fighting global warming and there is an initiative underway to develop a national strategy for community –based climate change adaptation (*National Environmental, Economic and Development Study (NEEDS) for Climate Change in Nigeria* 2010). The UNFCCC is an international environmental treaty with the goal of achieving the stabilization of green house gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Globally Nigeria contributes minimally to green house gas (GHG) emissions.

According to the *NEEDS for Climate Change (2010)* the most promising mitigation options in the Nigeria's energy system are:

a) Introduction of Compact Fluorescent Light (CFL) bulbs at a negative cost of 5/58/ton CO_2 with 5.155 in ton CO_2 reduction capacity.
b) Introduction of improved kerosene stove, in households, at a cost of $21/ton of CO_2 reduced (6-122m ton CO_2 reduction capacity).
c) Fuel-oil to natural gas fuel substitution in the cement industry at $18/ton (7.49m ton CO_2 reduction capacity)
d) Improve electrical appliance ($3/ton) in the residential sector (9.566m ton CO_2 reduction capacity)

e) Introduction of efficient motors in industry at $15/ton (10.738m ton CO_2) gaseous emissions such as H_25, SO_2 NO_2, CH_4, CO_2 and CO are not produced or if produced as

f) In the case of CH_4 during biogas production does not add to the global warming picture.

g) Afforestation (establishment of protected forest units) reforestation and reduction in deforestation.

h) Studies have shown that Nigeria is not performing as well as expected in envisioning the country's climate future and building dynamic response strategies, including adequate research and infrastructure development. A lot needs to be done in the area of climate change scenario analysis for both mitigation and adaptation response measures and their cost implications or aggregate basis. This should enable the country to plan very for its response to changes in its climatic conditions.

i) Biomass energy is another mitigation option to enable Nigeria meet her National Environmental Economic and Development Study (NEEDS) objective for climate change in Nigeria.

Biomass

This is a renewable energy source. It is a biological material from living or recently living organisms. As an energy source, biomass can either be used directly, or converted into other energy products such as biofuel.

Biomass energy may be plant matter used to generate electricity with steam turbines and gasifiers or produce heat, usually by direct combustion. Biomass energy may include plant or animal matter that can be converted into fibres or other industrial chemicals, including biofuels.

Biomass fuel (Biofuel)

These are fuels made from recently living organisms. They may either be liquid (biodiesel, ethanol) or gas (biogas).They can be divided into three categories.

- First-generation biofuels: These are made largely from edible sugars and starches
- Second-generation biofuels: These are from non-edible plant materials.
- Third-generation biofuels: These are made from algae and other microorganisms.

Biofuels are considered neutral with respect to the emission of CO_2 because the CO_2 given off by burning them is balanced by the CO_2 absorbed by the plants during their growth to produce them.
Ethanol produced by fermenting the sugars in biomass materials such as corn and agricultural residues is known as bioethanol.

Biodiesel is made by processing vegetable oils. It may be used in the pure form or as an additive to petroleum-based diesel fuel.

Biogas is a mixture of methane and CO_2 produced by the anaerobic decomposition of organic matter

such as sewage and municipal wastes. It can be used in the generation of electricity or for heating purposes.

Research contributions

Akubuenyi and Odokuma (2011) have generated biogas from municipal waste. The substrates used in their study were plantain peels, vegetable waste, beans, boiled rice and cow dung (80% waste and 20% cow dung). The wastes were shredded and mixed with water at the ratio of 1:3. They fed into bioreactor and allowed for a retention time of 30 days. The system generated a cumulative biogas production of 0.427m^3 on day 30. Passage of the biogas through a charcoal medium removed most of the CO_2 producing a gas consisting of 88% methane. The next stage in their research is to convert the chemical energy in the gas to electric energy in such a way that it can be used as a source of electricity in homes.

ENVIRONMENTAL STUDIES

These include Environmental Impact Assessment (EIA), Environmental Evaluation Reports (EER) and Post Impact Assessment (PIA) studies.

Environmental Impact Assessment (EIA)

Environmental Impact Assessment refers to the assessment of impacts of a project on the biophysical (ecology), health, social and economic environments.

The International Association for Impact Assessment (IAIA) defines an environmental impact

assessment as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made

Environmental Impact Assessment process is a step-by-step procedure to determine the likely effect (potential positive and negative effects) of a project on the surrounding environment (biotic and abiotic components) as well as the health, social and economic well being of the communities in the project area

EIAs are unique in that they do not require adherence to a predetermined environmental outcome, but rather they require decision makers to account for environmental values in their decisions and to justify those decisions in light of detailed environmental studies and public comments on the potential environmental impacts of the proposal

The EIA process ensures that mitigative actions are put in place that assist in the reduction of negative effects and enhancement of positive effects on the ecology, health and social wellbeing of the communities in the project area.

In Nigeria, the EIA is a statutory requirement for all categories of Petroleum exploration and Production (E&P) projects as well as some non-oil and gas projects. It is made mandatory by various legislations, which includes the Petroleum Act of

1969 and the EIA Act No. 86, of 1992. Environmental Impact Assessment covers three components, namely ecological, social and health environmental impact assessment.

The EIA process requires a multidisciplinary approach. It involves consultants of various specializations (experts in terrestrial, aquatic, geologic aerial systems etc), community stakeholders (traditional rulers, elders, youths, women etc), non-governmental organizations (NGOs) and regulatory bodies (e.g. Federal Ministry of Environment, State Ministries of Environment, Local Governments, Federal government Agencies and when oil and gas is involved the Department of Petroleum Resources)

There is growing dissent on the use of EIA as its influence on development decisions is limited and there is a view it is falling short of its full potential. There is a need for stronger foundation of EIA practice through training for practitioners, guidance on EIA practice and continuing research.
EIAs have often been criticized for having too narrow spatial and temporal scope. At present no procedure has been specified for determining a system boundary for the assessment. The system boundary refers to 'the spatial and temporal boundary of the proposal's effects'. This boundary is determined by the applicant and the lead assessor, but in practice, almost all EIAs address the direct, on-site effects alone.

Environmental Impact Assessment is not just for projects of large corporations such as oil and gas conglomerates or large Telecommunication firms. Government projects should also be subjected to EIA studies. In Nigeria today many large projects such as major roads by governments are not normally subjected to the EIA process. Meanwhile a lot of hue and cry is made by regulators who are part of government when multinationals fault during the EIA process. There is too much double standard in Nigeria. What is good for the goose is also good for the gander.

Both the Federal Ministry of Environment and the DPR have developed slightly different EIA processes and both these agencies drive the process.

Table 1.0: Summary of the EIA Process of FMEnv and DPR

S/N	FMEnv	DPR
1	Project Registration Project Proposal development Submission of Proposal Payment of EIA registration Fee	Development of Preliminary Impact Assessment Report(PIAR)
2	Site verification visit	Submission of PIAR
3	Categorisation(Category 1, 2 or 3) of the EIA	
4	Scoping Workshop	
5	Terms of Reference (ToR) Development	Terms of Reference (ToR) Development
6	Field work/Analyses	Field work/Analyses
7	Report Writing/IA process	Report Writing/IA process
8	Review Process	
9	Submission of Draft Report	Submission of Draft

		Report
10	Review Draft Report(Technical/Panel review)/Stakeholders Feedback	Review Draft Report
11	Obtain Provisional approval	Obtain Provisional approval
12	Submission of Final Report	Submission of Final Report
13	Obtain EIA Permit (Final approval/EIA Certificate	Obtain EIA Permit
14	Production of Environmental Impact Statement(EIS)	

Benefits of an EIA

In general the benefits of EIA include:
Enabling the likely significant environmental effects of a project to be identified and to be avoided, remedied or minimized at an early stage

Better environmental planning and design of a proposal. Carrying out an EIA entails an analysis of alternatives in the design and location of projects. This can result in the selection of an improved technology, which lowers waste outputs or an environmentally optimum location for a project. A well-designed project can minimise risks and impacts on the environment and people, and thereby avoid associated costs of remedial treatment or compensation for damage.

Ensuring compliance with environmental standards. Compliance with environmental standards reduces damage to the environment and disruption to communities. It also avoids the

likelihood of penalties, fines and loss of trust and credibility.

Savings in capital and operating costs. EIA can avoid the undue costs of unanticipated impacts. These can escalate if environmental problems have not been considered from the start of proposal design and require rectification later. An â€˜anticipate and avoided. Generally, changes which must be made late in the project cycle are the most expensive.

Reduced time and costs of approvals of development applications. If all environmental concerns have been taken into account properly before submission for project approval, then it is unlikely that delays will occur as a result of decision-makers asking for additional information or alterations to mitigation measures.

Increased project acceptance by the public. This is achieved by an open and transparent EIA process, with provision of opportunities for public involvement of people who are most directly affected by and interested in the proposal, in an appropriate way that suits their needs

Environmental Evaluation Report (EER)
Environmental Evaluation Report (EER) is the study of the impacts of existing facilities on the environment. It is carried out for regulatory compliance or for facility improvement.

An EER evaluates the performance of a facility with a view to ascertaining its impacts, if any, on the

environment. The report also contains definite recommendations for mitigation and amelioration of any impacts as well as monitoring strategies/plans.

Environmental evaluation is a structured environmental performance review of facilities and evaluation of potential impact or mitigation possibilities arising from inappropriate development, operations and or existing facilities. EER is therefore, an evaluation and performance review for facilities' vis-à-vis already polluted or impacted environment. All the interrelated activities of petroleum exploitation, transportation, refining, and marketing have come under the increasing scrutiny of an environmentally informed public and their governments.

This study is a DPR requirement and not a Federal Ministry of Environment requirement. It is mainly for brown fields in the oil and gas industry.

This DPR has developed guidelines and standards covering the control of the pollutants from the various petroleum activities in Nigeria, including, exploration, LPG/Natural Gas/LNG Plants, Blending Plants and Development Operations, Production, Terminal Operations, Hydrocarbon Processing Operations, Oil and Gas Transportation and Marketing. These guidelines are contained in a document called *Environmental Guidelines and standards in the Petroleum industry in Nigeria* (EGASPIN)

This document EGASPIN provides the relevant legal requirements concerning gaseous emissions, effluent, noise levels and waste disposal practices. The DPR issues permits for all aspects of oil related effluent discharges from point sources (gaseous liquid and solid) and oil related project development.

Thus no operator is permitted to discharge any effluent without a permit. These permits (notices, orders, consents, or demands) are usually in writing. The format is prescribed by the Directorate of Petroleum Resources and used in all cases to which the forms are applicable.

The EER process requires a multidisciplinary approach. It involves consultants of various specializations, community stakeholders, non-governmental organizations (NGOs) and regulatory bodies DPR, State Ministries of Environment, Local Governments, and Federal Government Agencies.

An EER is aimed at achieving the following objectives:

- Provide detailed information on the condition of the environment within which a facility is located.
- Determine the impacts of the facility on the environment
- Examine and assess the environmental components that are impacted
- Assess the severity of impacts on the natural, social and health environments, by

comparing with previous baseline data (where it exists) and regulatory standards

- Recommend measures for the mitigation of adverse impacts identified
- Provide detail of a management plan for the continued operation of the facility or the restoration plan in case of facility abandonment

Table 2.0: Stages of an EER

S/N	STAGES
1	Initiation of PIA or EER
2	Scoping Process
3	Development of Terms of Reference (ToR)
4	Field data collection/ Laboratory Analysis
5	Evaluation and Assessment of Impacts/ Report writing
6	Report Review

Post Impact Assessment (PIA)

This is the study of an environment that has been impacted due to development activities such as dredging, land clearing and construction or due to oil and chemical spillage, etc. The study is usually carried out in order to comply with Government regulations and/or to demonstrate care for the environment.

It is a requirement for both the Federal ministry of Environment and the Department of Petroleum resources

A PIA study is aimed at achieving the following objectives:

- Provide detailed information on the extent of impact to the environment
- Examine and assess the environmental components that are impacted
- Assess the severity of impacts on the natural, social and health environments, by comparing with baseline data (before impact where it exists) and regulatory standards
- Recommend and evaluate methods for effective restoration of the site in accordance with the regulatory requirements

The PIA process requires a multidisciplinary approach. It involves consultants of various specializations, community stakeholders, non-governmental organizations (NGOs) and regulatory bodies (e.g. Federal Ministry of Environment, State Ministries of Environment, Local Governments, Federal government Agencies and when oil and gas is involved the Department of Petroleum Resources)

Table 3.0: Stages of a PIA

S/N	STAGES
1	Initiation of PIA or EER
2	Scoping Process
3	Development of Terms of Reference (ToR)
4	Field data collection/ Laboratory Analysis
5	Evaluation and Assessment of Impacts/ Report writing
6	Report Review

Research contributions

In most EIA and PIA final reports, the section on biodiversity is usually used interchangeably with wild life. These two terms are however, not the same. Biodiversity is the variability in living systems within the area while wild life refers to fauna such as birds, reptiles, amphibians and mammals within an area. As a consequence of this we have developed a reporting format for biodiversity reporting in EIA and PIA reports.

BIODEGRADATION MODELING

Testing biodegradation has become an important step in the design, development and registration of a chemical product. While conducting biodegradation tests several unspecified microorganism species interacts with the test compound and its (mostly unknown) degradation products, yielding, in the case of a compound passing the test the additional information of no obvious toxicity of parent compound and major degradation products against the organism responsible for biodegradation in the respective experiment.

Biodegradation models are examples of mathematical models. A mathematical model is a description of a system using mathematical concepts and language. A model may help to explain a system and to study the effects of different components, and to make predictions about behaviour. Mathematical models can take many forms, including but not limited to dynamic systems, statistical models, differential equations, or game theoretical models. In many cases, the quality of a scientific field depends on how well the

mathematical models developed on the theoretical side agree with results of repeatable experiments. Lack of agreement between theoretical mathematical models and experimental measurements often leads to important advances as better theories are developed. The benefits of mathematical models include prediction of future events / events that would occur in given circumstances, e.g. calculating the absolute zero temperature. However there are limitations as you project further into the future/unknown conditions-you can't rely on those projections to be accurate if your raw data was not from several years ago or from temperatures around room temperatures around room temperature.

There are many reasons to model biodegradation. One reason is that there are many more man-made chemicals produced that can experimentally be tested for biodegradation within a reasonable time frame and at reasonable cost. Another is that incomplete degradation results in numerous and often unknown transformation products not accessible to experimental testing. Furthermore, in recent years the benign by testing concept is more and more acknowledged, i.e. considering proneness to degradation early in the development of a chemical product, even before synthesis. For these reasons computation modeling and prediction of biodegradation of chemicals is gaining increasing importance

Whenever a compounds pollution status is discussed its biodegradation in wastewater

treatment plants and in surface waters is considered first, since fast and complete mineralization will obviously remove any concern.
There were two major lines of research in modeling and predicting the biodegradation of structurally diverse organic compounds. The first line attempts to describe by predictive models biodegradation rates or the extent of biodegradation within a fixed time and to classify compounds as readily/not readily biodegradable without caring much about the identity of intermediate pathways (Rucker and Kummerer, 2012).

The second line of research tries to describe and predict products and pathways of biodegradation without, initially, focusing on quantification (Rucker and Kummerer, 2012).

These methods describe and predict the propensity to aerobic degradation in water by mixed bacterial populations. In such models counts of structural fragments are used as descriptors.
Example of biodegradation models include, Biowin (Bowin1,2,3,4,5,6,7) models, TOPKAT and Catabol, Multicase, UM-PPS, PathPred, Catabol/Catalogic and BDPServer models(Rucker and Kummerer, 2012).

In Nigeria one model that has been developed and employed for the prediction of oil spill fates (physical, chemical and biological degradation) is the Nigerian Oil Spill Model (NOSM).

$$\frac{\partial M}{\partial t} \propto t$$

$$\frac{\partial M}{\partial t} = Kt$$

M=(Mo)exp (-Kt)

Where:
M = mass of the oil
Mo = initial mass of the oil
K = empirical decay coefficient
t = time.

Contributions

The limitations of this Nigerian Oil Spill model are as follows:

(a) it does not monitor the total biomass of the microorganisms involved in biodegradation.

(b) It is based on a first order reaction mechanism which does not reflect natural systems which are actually a combination of first, second and third order reactions.

(c) It is an over simplistic model which does not take into cognizance reactions in the aqueous phase, sediments, etc.

As we are aware this is an over simplistic assumption and it is not close to natural conditions biodegradation is treated as a first order decay process in which the oil biodegraded is proportional to the initial mass and an empirical decay coefficient. However, Odokuma and Williams (2010, 2012) have proposed a modification to this model.

They simulated the fate of a crude oil slick (930m^3) in a brackish water system of 1.5m^2 (medium oil spill) in a solid phase continuous flow biodegradation system and employed the MATHSLAB/SIMULINK soft ware to modify the NOSM model. The proposed model takes into account the total biomass of microorganisms, electron acceptors (oxygen, nitrate) involved in biodegradation in addition to mass of crude and time. Finally it assumes that biodegradation reactions may either be first, second, third or a combination of three orders. Been a higher order model, it is a good reflection of natural systems. The coupling of the proposed biodegradation model with NOSM presents a more complete picture on the fate of the oil spill in a brackish water system.

The proposed biodegradation model is a partial differential equation as follows:

Substrate loss in the bulk fluid;

$$\frac{\partial C_i}{\partial t} = \sum_{k=1}^{X_k} \frac{C_i}{\left[\mu_{\max} X_k \left(Ks\left(1+\sum_{j=1}^{X_k} \frac{C_i}{Ks}\right)+C_i\right)\right]}$$

Substrate loss in biomass

$$\frac{\partial C_i}{\partial t} = \sum_{j=1}^{X_k}\left(\frac{-BX_K}{m(C_1-C_2)}\right) - \sum_{j=1}^{Xs}\left(\mu_{\max}\left(\frac{C_i}{K_s\left(1+\sum \frac{C_i}{Ks}\right)}\right)\right)$$

Where:

Ci = Concentration of species in the bulk liquid (Mass C / volume of aqueous phase).

XK = Concentration of biomass.

C_1= Initial concentration.

C_2= Final concentration.

Ks = Monod half saturation constant.

K = Biological species.

μ_{max} = Monod maximum growth rate.

i = Substrate.

j = Electron acceptor.

m = Mass of a single colony (mass / colony).

t = Time.

ß = Surface area of a single bacterial colony available for mass transfer.

Xs = Concentration of substrate.

Trajectory Studies

Simulating an oil spill in the New Calabar River near Eagle Island the trajectory of the oil spill was investigated employing MapInfo GIS software. Wave driven current equation was coupled with that of wind drift current, ocean current, tidal current and long shore current for adverting oil spill on coastal waters. The results from a hypothetical spill site with actual spill position was on latitude 4^o 47 -N and longitude 6o 58- and 7^0 00 showed that simulated oil spill for wet season reached New Calabar river in 1620 seconds (27min) and 2747 seconds (45.78mins) during the dry season. Speed and direction of wind drift current, speed and direction of surface wave drift current, speed and direction of tide, speed and direction of ocean

current, speed and direction of long shore current were employed in the calculation.

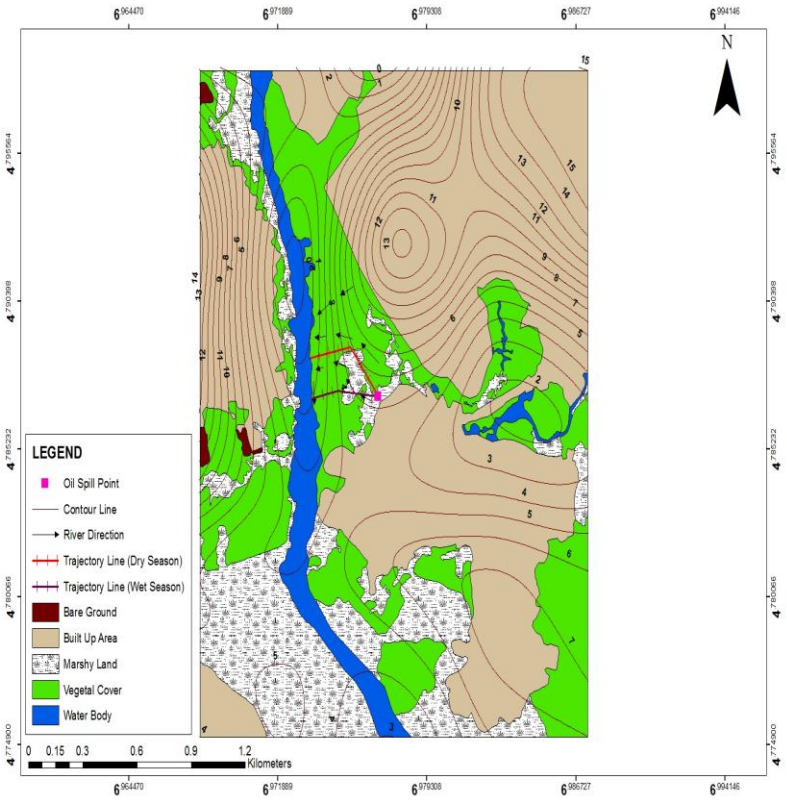


Figure 14: Oil spill trajectory

FUTURE RESEARCH

Carrying Capacity of Environment

Carrying capacity refers to the size of a population that can live in an environment without doing that environment any harm. Currently there exists no acceptable model for determining carrying capacities of habitats/ecosystems. DPR EGASPIN procedure for environmental monitoring makes carrying capacity determination a must do. However DPR does not provide a methodology for the process. Odokuma *et al (*2008) have suggested methodology and a model for determining carrying capacity. We intend to improve on this model.

Biocorrosion Models

Develop a model that will be employed in the prediction and quantification of biocorrosion rates in brackish and freshwater systems in the Niger Delta.

Biodegradation Models

We are going to subject our biodegradation model to more scenarios and see areas where it could be improved upon.

Climate Change/Global Warming

Study the impact of global warming on biodegradation rates in different habitats in the Niger delta

Biomass Energy

Investigate a host of commonly encountered agriculture waste materials or composites that may serve as alternative and better substrates to

existing ones for biogas generation. Studies shall also be geared towards improvement on the engineering design of biogas reactors with the objective making these products cheaper, more efficient, less complicated and readily available to the common man.

Microbial mats

Microbial mats of different microbial composition will be produced and tested in the treatment of crude oil polluted coastal habitats and industrial effluents.

CONCLUSION

Microorganisms especially bacteria are geniuses their simplicity, relative to other organisms notwithstanding. Their dexterity and versatility has provided opportunities which other forms of life may not have. They are critical and indispensable for the management of xenobiotic mediated environmental flux.

Their role in terrestrial and aquatic pollution mitigation is unrivalled. Biodegradation (natural attenuation or bioremediation) is responsible for the ultimate removal of pollutants such as spilled crude oil from the environment. Without biodegradation accumulation of these compounds would have reduced the quality (aesthetics, economic, agricultural and cultural) of the environment. Microbial mats have been employed in remediation of polluted aquatic systems and water purification for domestic uses

Early warning detection of pollutants in ecosystems by biomonitoring is an efficient method for preventing environmental degradation. Trend analyses of ecological quality parameters provide information for assessing environmental performance by industry. Environmental performance monitoring enables production with minimal negative impact to the environment
Ecotoxicological studies enable determination of the effect of a pollutant on indigenous biota of receiving systems. It also provides information on the morphological, physiological and behavioral effects of these organisms.

Bioaccumulation provides information on the concentration and the effects of a pollutant in the tissue of biota in receiving systems. Biomagnification studies prevent the outbreak of diseases as a result of ingestion of heavy metal contaminated biota as food. Bioadsorption is employed in clean-up of heavy metals and organics from polluted receiving systems

Biocorrosion monitoring and mitigation may assist in reducing the spate of pipeline ruptures along the thousands of kilometers of pipelines Right of Ways (RoW) in the Nigerian Petroleum Industry. This will save oil and gas companies associated with upstream activities in the petroleum industry from numerous incidences of litigation, clean-up activities and other issues relating to community unrests.

The use of alternative /green energy sources such as biofuel/biogas should be promoted. The substrates for biomass energy abound in our environment. The technology is relatively simple. It is clean. However, the resolve to use it needs to be developed. Capital is also required to mass produce bioreactors and it's appendages to make it affordable to the common man as an alternative to kerosene stoves.

Inadequate or no planning has given rise to adverse impacts of industry in the environment. The discharge of waste streams such as emissions and effluents in the environment would have been prevented if EIAs were conducted and their out puts used. Conducting EIAs and implementing their results will ensure sustainable development.
Modeling of environmental fate of pollutants is cheaper and less time consuming than actually performing laboratory and field simulations. Modeling provides rapid answers to questions resulting from the development of new chemicals and their environmental fates. We are able to create real life scenarios from models which assist in prediction. Prevention is better than cure.

RECOMMENDATIONS

Periodic retraining of academic staff to be abreast of new trends in their various areas of specialization is critical for the development of the academic and the production of quality products (graduates) that are competitive and meet industrial and societal requirements.

University- Industry partnership should be strengthened so that academia are aware of the needs of industry and subsequently proffer implementable and innovative solutions for these needs. Industry should encourage academia to spend some time with them so that academia can familiarize themselves with operations of industry. This will expose academia to the needs and complexities of industry and expand their thought process.

Tertiary education is expensive. Governments, Industry, Entrepreneurs and Non Governmental Organizations should be encouraged and made to invest in education. The most educated societies are advanced societies.

Universities should create enabling atmosphere for research. Researchers should be adequately funded, motivated and rewarded.

Existing academic curricula should be made to reflect current industrial and societal needs. Obsolete curricula should be deemphasized.

Environmental regulating Ministries and Agencies such as the Federal Ministry of Environment, State Ministries of Environment, DPR, NOSDRA, and National Environment Standards Regulating and Enforcement Agency (NESREA) should be financially and technologically equipped to meet present day environmental challenges. For instance they should not depend on the oil and gas companies for logistics. They should also be

abreast of current technological trends in the specific areas of the environment that they are inspecting/monitoring.

Multiple regulation or multiple regulators in the environment industry seem impact negatively on project schedule and consequently increase cost of projects. For instance in an attempt by DPR to show that they are relevant in the petroleum industry they establish different pathways from that of the Federal Ministry of Environment who believe that they are more relevant. Also look at the issue between the Nigeria Communication Commision (NCC) and NESREA with regards EIA for GSM masts.

Government projects requiring EIA must be subjected to the EIA process if EIA is truly an important process.

Gaps still exist in the EGASPIN procedure for toxicity testing. When performing tests for effluents or produced water discharged in to marine (seawater or oceans) the document is silent on organisms to be used for the tests. As a result experimenters use recommended brackish water shrimp (*Palaemonetes africanus*) which are not indigenous or real representatives of marine environments. This is a serious gap in the toxicity protocol which needs to be solved. DPR needs to agree on marine organisms that can be used for this test.

REFERENCES

1. Adoki. A. A and **Odokuma L. O.** (2007). Bioluminescent Hydrocarbonoclastic bacteria of the Niger Delta. *African Journal of Biotechnology* 6(4):393-399

2. Aelion, C. M., Swindoll, C. M. and Plaonder, F.X. (1987) Adaptation to and biodegradation of xenobiotic compounds by microbial communities from pristine aquifer. Applied and Environmental Microbiology 53:2212 - 2217

3. Alexander, M (1994) Biodegradation and Bioremediation. Academic Press, San Diego pp25-56

4. Allsopp, D and Seal, K. J.(1986)Introduction to Biodeterioration. Edward Arnold (Australia)Pty Ltd, Victoria Australiapp1-133

5. Arika, R. M. BirminYamri, A.U. and Chinoko, J.U. (1998).Analyses of some environmental pollutants within Sokoto Metropolis. *Symposium on Chemistry and Biotechnology for National Development*. Shoda Science and Technology Complex, Abuja pp153-155

6. Atlas, R. M and Bartha, R (1998) *Microbial Ecology Fundamentals and Application*s 4th edition pp 27-55

7. *Environmental Guidelines and Standards in the Petroleum Industry* (EGASPIN) (2002) Department of Petroleum Resources (DPR) Lagos

8. Espy, H. H.(1995) The chemistry of wet strength Broke Repulping, *Progress Paper Recycling* 1(4):17

9. *Federal Ministry of Environment National Guidelines and Standards for Water Quality in Nigeria* (1991)Federal Ministry of Environment Nigeria

10. Ford, T. and Mitchel, R. (1992) Microbiology Transport of toxic metals. In; *Environmental Microbiology*. A.J.Wiley and Sons Incorporated New York pp83-97

11. *Holy Bible, New international Version(*1984)International Bible Society, Colorado Springs pp1-2

12. Ifeadi, C. N., Nwankwo,J.N., Ekaluo, A.B. and Orubima,I. I. (1985). Treatment and disposal of drilling muds and cuttings in the Nigerian Petroleum Industry and the Nigerian Environment. In *Proceedings of the 1985 International Seminar Nigerian National Petroleum Corporation,* Lagos 55-58

13. Javaherdashti,R., Nikiraz,H., Borowitzka, M., Moheimani,N. and Olivia, M. (2009)the impact of algae on accelerating the biodeterioration/biocorrosion of reinforced

concrete. A mechanistic review. *European Journal of Scientific Research* 36(3)394-406

14. Jones, M.M. Johnston, D.O., Netterville, J.T., Wood, J.C. and Joeston, M.D (1987)*Chemistry and Society* 5th edition CBS College Publishing Company USA p608

15. Lee, K and Levy, E.M (1991)Bioremediation of waxy crude oils stranded on low energy shorelines. In *Proceedings of the 1991 International Oil spill Conference.* American Petroleum Institute Washington D.C. pp541-547

16. *Longman Dictionary of Conteporary English* (2007)Pearson Education Limited, Edinburgh

17. Malekzadeh, F, Farazmand, A., Ghafourian, H., Shahamar, M., Levin, M., Grim, C. and Colwell, R.K. (1995) Accumulation of heavy metals by a bacterium isolated from Electroplating Effluents. *Proceedings of the biotechnology Risk Assessment Symposium,* Canada pp388-398

18. Muhlemann, T. N.(1986) Guide to drilling completion and work over fluids World Oil 202 Gulf Publishing Company, Houston Texas

19. *National Environmental, Economic and Development Study (NEEDS) for Climate*

Change in Nigeria (2010). Federal Ministry of Environment

20. *National Occupational Health and Safety Commission* (NOHSC) (1994). National code of Practice for the Preparation of Material Safety data sheets NOHSC: 2011 Canberra Australian Government Publishing Services

21. Odiete, W.O. (1999) *Environmental Physiology Animals and Pollution*. Diversified Resources Ltd University of Lagos, Lagos pp210-246

22. **Odokuma, L.O** and Okpokwasili, G.C. (1992) Role of Composition in Degradability of oil spill dispersants. *Waste Management* 12: 37-43

23. **Odokuma, L.O**. and Okpokwasili G.C (1993) Seasonal Ecology of hydrocarbon-utilizing microbes in the surface waters of a river. *Environmental Monitoring and Assessment* 27: 175-191

24. **Odokuma, L.O.** and Okpokwasili G.C (1993) Seasonal Influences on Inorganic Anion Monitoring of the New Calabar River Nigeria. *Environmental Management* 17(4): 491-490

25. **Odokuma, L.O**. and Okpokwasili G.C., (1997). Seasonal Influences of Organic pollution monitoring of the New Calabar

River, Nigeria. *Environmental Monitoring and Assessment* 45: 43056

26. **Odokuma, L.O.** and Ibe, O.C. (2003). Biodeterioration of Paper and Plastics using free Immobilized Microbial Cells. *Nigerian Journal of Microbiology* 17 (1) 17 -25

27. **Odokuma, L.O**. and Ibor, M.N. (2002). Nitrogen Fixing Bacteria Enhanced bioremediation of a crude oil polluted soil. *Global Journal of Pure and Applied Sciences* 8(4): 455 - 468

28. **Odokuma, L.O** and Dickson, A.A. (2003). Bioremediation of a Crude Oil Polluted Tropical Rain Forest Soil. Global *Journal of Environmental Sciences*. 2(1): 29 - 40

29. **Odokuma, L.O**. and Okpokwasili G.C. (2003). Response of Microbial Enzymes Synthesis to Toxicity of Weathered and Biodegraded Crude Oils. *Global Journal of Pure and Applied Sciences* 9(2): 183 - 191.

30. **Odokuma, L.O**. and Ijeomah S.O. (2003). Tolerance of Bacteria to Toxicity of heavy Metals in the New Calabar River, *Global Journal of Environmental Sciences* 2 (2):128 - 132

31. **Odokuma, L.O and Tsegne**, I.I. (2003). Microbial Stability of some Nigerian Paints Manufactured in Aba, Abia State *Nigeria.*

Journal of Polymer Science and Technology 3 (1): 193 - 201

32. **Odokuma, L.O.** and Ijeomah, S.O. (2003). Seasonal Changes in the Heavy Metal Resistant Bacterial Population of the New Calabar River. *Global Journal of Pure and Applied Sciences.* 9 (4): 425 - 433

33. **Odokuma, L.O**. and Ibor, M.N. (2003 Bioremediation of a crude oil polluted tropical soil by Nutrient Supplementation. *Scientia Africana*. 1 (2): 1 - 11

34. **Odokuma, L.O** and Dickson, A.A 2003). Bioremediation of a Crude Oil Polluted Tropical Mangrove Swamp. Nigerian Journal of Applied Science and Environmental Management 7 (2): 23 - 29

35. **Odokuma, L.O**. and G.S.C. Okpokwasili (2003). Bacterial Enzyme Induction Inhibition as a tool for Ecotoxicity Assay. *Global Journal of Pure and Applied Sciences*. 9(3) 311-318

36. **Odokuma, L.O**. and H.I. Ogbu (2002). Tolerance of Bacteria and Crustaceans to oil spill dispersants. African Journal of Applied Zoology and Environmental Biology. 4:50 - 55

37. **Odokuma, L.O**. and I. B. Kindzeka (2003). Response of *Nitrobacter, Desmocaris*

trispinosa and *Metylis edulish* to toxicity of soil spill dispersants. *African Journal of Applied Zoology and Environmental Biology*. 5: 14 - 20

38. **Odokuma, L.O.** and Ikpe, M. O. (2003). Role of Composition in the Degradability and Toxicity of Drilling Muds. *African Journal of Applied Zoology and Environmental Biology*. 5: 6 - 13

39. **Odokuma, L. O**. and Abah, A.E. (2003). Heavy Metal Biosorption by three Bacteria Isolated from a Tropical River. *Global Journal of Environmental Sciences*. 2 (2):98 - 101

40. **Odokuma, L.O**. and Oliwe, S. I., (2003). Toxicity of Substituted Benzene Derivatives to four Chemolithotrophic Bacteria. *Global Journal of Environmental Sciences*. 2 (2): 72 - 96

41. **Odokuma, L.O.** and Otokunefor, K. (2003). Primary Biodegradation and Ultimate Biodegradability of Hair Shampoos in fresh, brackish and marine water of the Niger Delta. Global Journal of Environmental 2 Sciences. 2 (2): 88 - 95.

42. **Odokuma, L. O**. and Osuagwu, C., (2004). Tolerance of Chemolithotrophic bacteria to organochlorine, organophosphate and carbamate pesticides. *Journal of Agriculture*

and Environmental Engineering Technology 1(1): 7-15.

43. **Odokuma, L. O**. and Akpokodje, E. G., (2004). Biodegradation of simulated landfill Leachate in tropical soil of depth 6.5 metres. *Journal of Applied Science and Technology* 4(1): 6-14.

44. **Odokuma, L. O**. and Akponah, E. (2004). Inhibition of nitrification and Carbon dioxide evolution as rapid tools for ecotoxicological assessment of drilling fluids. *African Journal of Applied zoology and environmental biology*. 6:16-24

45. **Odokuma, L. O.** and Emedolu, S. N., (2005). Bacterial Sorbents of Heavy Metals Associated with Two Nigerian Crude oils. *Global Journal of Pure and Applied Sciences*. 11(3):343-351

46. **Odokuma, L. O**. and Nwaokeleme, A. C. (2005). Biodegradability of Cell phone recharge cards in fresh, brackish and marine waters of the Niger Delta. *Nigerian Journal of Microbiology.* 19 (1-2):611-622

47. **Odokuma, L. O**. and Omunakwe, F. N. (2004). Biodegradability of four household insecticides. *Journal of Agriculture and Environmental Engineering Technology*.1 (1): 126-134

48. **Odokuma, L. O**. and Okey, V. I. (2004). Biodegradability of Electrostatic Photocopier toners. *Tropical Freshwater Biology*.14: 95-107

49. **Odokuma, L. O.** and Okara, J. O. (2005). Biodegradability of Grounded Cell phone recharge cards in two Niger Delta soils. *Journal of Applied Sciences and Technology* 5(1-2):11-20

50. **Odokuma, L. O**, Ezenwaka, E, Ezeaku, E and Aguiyi, D. (2006.) Gaps in Existing Guidelines and Procedures for Acute and Chronic Toxicity tests and Suggested Modification The 12th *International Conference on the Oil and Gas Industry in Nigeria*, Department of Petroleum Resources Calabar2006

51. **Odokuma, L. O.** and Smith, V. A. (2007). Biodegradation of a Nigerian crude oil by *Chroococcus* and *Chlorella* species. *Tropical Freshwater Biology* 16(1):17-30

52. **Odokuma, L.O.** and Isirima, J.C. (2007). Distribution of Cyanotoxins in aquatic environments in the Niger Delta. *African Journal of Biotechnology* 6(20): 2375-238

53. **Odokuma L O** and Akubuenyi F C.(2008). Effect of agricultural pesticides on the Crude oil loss in a medium spill impacted

tropical soil. *African Journal of Biotechnology* 7(4): 459-471

54. **Odokuma, L. O**, Ezenwaka, E, Ezeaku, E and Aguiyi, D. 2006. Gaps in Existing Guidelines and Procedures for Acute and Chronic Toxicity tests and Suggested Modification *The 12th International Conference on the Oil and Gas Industry in Nigeria*, Department of Petroleum Resources Calabar2006

55. **Odokuma, L. O**, E, Ezeaku,E. E. and Ezenwaka,I.C., 2008.A Proposed Mathematical Model for Determining the Carrying Capacity of Estuarine Aquatic Ecosystems in the Niger Delta. *The 13th International Conference on the Oil and Gas Industry in Nigeria*, Department of Petroleum Resources Abuja

56. **Odokuma, L.O**., Ezeaku, E .E., Ezenwaka, I. C. and Ejiofor, A.O. (2008). Trend Analyses of identified Environmental Quality Parameters in Shell Petroleum Development Operations. *The 13th International Conference on the Oil and Gas Industry in Nigeria*, Department of Petroleum Resources Abuja

57. **Odokuma, L. O.** and Akponah, E. 2008. Response of *Nitrosomonas, Nitrobacter* and *Escherichia coli* to drilling fluids. *Journal of Cell and Animal Biology* 2(2) 043-054

58. **Odokuma, L.O.** and Akponah. E. 2010. Effect of Nutrient Supplementation on Biodegradation and Metal uptake by three Bacteria in crude oil Impacted Fresh and Brackish waters of the Niger Delta. *Journal of Cell and Animal Biology* 4(1):1-18

59. **Odokuma, L.O.** and Akponah. E. 2010. Effect of Concentration and Contact time on heavy metal uptake by three bacterial Isolates. *Journal of Environmental Chemistry and Ecotoxicology* 2(6):84-97

60. **Odokuma, L.O.** and Akponah. E. 2009. Effect of Culture age and Biomass concentration on heavy metal uptake by three axenic bacterial cultures. *Advances in Natural and Applied Sciences* 3(3)339-349

61. **Odokuma, L.O** and Ugboma, C.J. 2011. Microbial Corrosion of Steel coupons in a freshwater Habitat of the Niger Delta *Journal of Ecology and Natural Environment* 3(12) 1-9

62. **Odokuma, L.O**. and Williams, J. O. 2010. Mathematical Modeling of Oil spills in an aquatic System by Coupling Nigerian Oil Spill Model with Solid Phase Continuous Flow Biodegradation. The 14th *International Conference on the Oil and Gas Industry in Nigeria,* Department of Petroleum Resources Abuja

63. **Odokuma, L.O.** and Williams, J. O. 2012.A Mathematical Model incorporating the influence on the fate of simulated oil spill in a brackish aquatic system. *British Journal of Climate Change*

64. Okpokwasili, G.C and **Odokuma L.O.** (1990. Effect of Salinity on Biodegradation of Oil Spill Dispersants. *Waste Management* 10. 141-146

65. Okpokwasili, G. C **Odokuma L.O**. 1994 Tolerance of Nitrobacter to Toxicity of some Nigerian crude oils. *Bulletin of Environmental Contamination and Toxicology* 5 (3) 388-395

66. Okpokwasili, G.C. and **Odokuma, L.O**., 1996 Response of Nitrobacter to toxicity of drilling chemicals *Journal Petroleum Science and Engineering* 16 81-87

67. Okpokwasili, G.C. and **Odokuma, L.O**. 1996 Tolerance of *Nitrobacter* to toxicity of hydrocarbon fuels. *Journal of Petroleum Science and Engineering* 17: 86-93

68. Okpokwasili, G.C. and **Odokuma, L.O**. 1997. Response of *Nitrobacter* to toxicity of oil spill dispersants and domestic detergents. *Tropical Freshwater Biology*. 6:65 – 74.

69. *Preparation and Implementation of Environmental Management Plan* Shell Petroleum Development Company (2004)

70. Rucker, C and Kummerer, K (2012)Modeling and Predicting Aquatic, Aerobic biodegradation-a review from a user's perspective. *Green Chemicals*

71. Stanier, R. U., Adelberg, E.A. and Ingraham, J.L(1982) *General Microbiology* 4th edition New York

72. Shumate, J.E., Strandberg, C.N. and Parrot, J. R. (1995). Microbial cell as biosorbents for heavy metals, accumulation of uranium by *Saccharomyces cerevisiae* and *Pseudomonas aeroginosa. Applied and Environmental Microbiology* 4:237-245

73. Swisher, R.D.(1987) *Surfactant, Biodegradation* 2nd edition Marcell Decker, Incorporated, New York

74. *United States Environmental Protection Agency*(USEPA) (1989)

75. Volesky, B. and May-Philips (1995) Biosorption of heavy metals by *Saccharomyces cerevisiae. Applied Microbiology Biotechnology* 42:797-806

CITATION ON PROFESSOR LUCKY OBUKOWHO ODOKUMA

Our 87th inaugural Lecturer Prof Lucky Obukowho Odokuma was born on the 26th of October, 1963 in Ovu, Ethiope East Local Government Area of Delta State, Nigeria. In November 1964 his mother left him in the care of his maternal grandparents and travelled to England to meet his father who had earlier left in December 1963 for a course in England. In 1968 he joined his parents in England where he had his primary school education. He attended Camelot Junior School London from 1968 -1974. He returned to Nigeria with his parents in 1974 and attended Eghosa Grammar School, Benin City from 1974-1979. He did his Higher School Certificate (Advanced Levels) from 1979-1981. He attended the University of Port Harcourt from 1982-1986 where he obtained a B.Sc (Microbiology)

1986, MSc (Industrial Microbiology) 1988 and PhD (Environmental and Petroleum Microbiology) 1991.

He did his NYSC in Shitire Community Secondary School, Tor-Donga, Katsina-Ala Local Government Area of Benue State in 1986-1987. He taught integrated science to class 1and 2 students and physics, chemistry and biology to class 3, 4 and 5 students.

As an undergraduate student in the department of Microbiology University of Port Harcourt during the 1984-1985 academic sessions he was elected editor-in chief of the Nigerian Association of Microbiology Students (NAMS).

In 1988 he was elected as Secretary of the Graduate Hall Management Committee. In 1989 he midwifed the formation of the Graduate Students Association and was later elected its first President in the same year. This association has now metamorphosed to the Graduate Students Union. His tenure as President witnessed increased respect for Graduate Students within the University.

On completion of his PhD programme in 1991 he was employed in the department of microbiology as a lecturer II. In 1994 he was promoted to Lecturer I and in 1997 to Senior Lecturer. He became the first product of the department to be employed in the department and subsequently head the department during the 2001-2003 academic sessions.

During his tenure as HOD (2001-2003) the department of microbiology was adjudged the best organized department in the Faculty of Science. Its semester and degree results were always the first to be ready. Results were computerized and there was tremendous cooperation between all members of staff. The organization of the department was unrivalled. For instance only graduating students of the department of microbiology joined the first batch of 2002/2003 National Youth Service from the Faculty of Science. He earned a commendation from the then Dean of Science, Prof B. E. Okoli as the best HOD in the Faculty. He was always guided by a verse in the Holy Bible "*when the righteous rule the people rejoice"* Proverbs 29:2.

In 2004 he was appointed as the first Director of the Institute of Science Laboratory Technology (ISLT) now School of Science Laboratory Technology (SSLT). The reputation of the ISLT was at its lowest ebb and there was need to raise the game. Guided by the same Bible verse (Proverbs 29:2) he plunged into action. Within one year the game was raised, the reputation improved and a new B.Sc programme (Bachelor of Science Laboratory Technology) was born approved by Senate Committee on Academic Planning and Programmes (SCAPP) and implemented. In 2005 the newly developed curriculum was used as a template by the Nigerian Institute of Science Laboratory Technology (NISLT) for the Bachelor of Science laboratory technology programmes in the country and received the commendation of the Registrar/Director General/CEO of NISLT, Dr I.F

Ijagbone. He is currently a member of the academic board of the School of Science Laboratory Technology, University of Port Harcourt the new status of the Institute of Science Laboratory Technology.

In his quest to assess the environment through the corporate eye, he accepted a sabbatical position (Environmental Adviser) in Shell Petroleum Development Company (SPDC), Nigeria Ltd. He was an asset to the organization. Though he was posted to the Biodiversity unit, it was obvious his wealth of experience was required in other sections of the department. He performed a rare feat, what no other sabbatical staff had done before and is yet to rival. He worked in all the existing units within the Corporate Environment Section of SPDC, Impact assessment, Environmental Monitoring, Post Impact Assessment, Environmental Reporting in addition to Biodiversity. In SPDC parlance he added tremendous value to business. In recognition of this he was appointed as an Environmental Consultant for the SPDC Environmental and SODA teams. During his sabbatical he jointly authored a number of corporate publications.

In his capacity as Environmental Consultant to SPDC, he has supervised and obtained EIA approvals (waivers, provisional and final approvals) from both the Department of Petroleum Resources (DPR) and the Federal Ministry of Environment (FMEnv), for a number of Projects of national importance (including the Utorogu Non Associated Gas Plant 2, which is vital for Nigeria's quest to

meet her domestic gas production and energy requirements. He is currently involved in the supervision of EIAs for a number of domestic gas related projects.

He has represented SPDC in a number of national and international conferences where he has presented a number of papers on topical environmental issues.

He is also a Consultant Ecologist to the Federal Ministry of Environment. In this capacity he has served as EIA Technical review Panel Chairman/Member and Ecology Consultant for a number of EIA studies monitored by the Federal Ministry of Environment.

He has served as an Environmental Consultant to Nigerian Agip Oil Company (NAOC) and Wilbros (now known as Ascot onshore and offshore Nigeria)) where he has been involved in a number of EIA and groundwater potability studies.

He is a member of the Consultancy and Research Development Center (CORDEC) of the University of Port Harcourt where he has served as consultant Microbiologist and ecotoxicologist in a number of EIA, Post Impact Assessment and Ecotoxicological Studies.

Since 1989 he has been actively engaged as an Environmental consultant to a number of other consultancy firms such as Prodec-Fugro, now (Fugro Consultants), Energy Resources, Atlantic

Wastes, Quality Control and Testing Laboratories, Hybrid Technologies, Biotics, Kitiwake, Mcmathy and Nantipol to mention but a few. In these companies he served as consultant Ecologist, Microbiologist, Ecotoxicologist Bioremediation specialist, Waste Management specialist, Environmental Monitoring specialist, Training Resource Person and Environmental Team leader.

In 2005 he was promoted to the rank of Associate Professor of Environmental and Petroleum Microbiology and in 2009 to the rank of Professor of Environmental and Petroleum Microbiology. He has a number of publications to his credit. He has over 50 journal articles in national and international journals, 10 articles in national and international Proceedings and 10 books jointly authored.

He has reviewed articles for a number of national and international Journals. These include, *Nigerian Journal of Microbiology, Scientia Africana, African Journal of Biotechnology, International Journal of Biotechnology* etc.

He has been an external examiner for undergraduate/Post graduate student's theses in many universities including Universities of Uyo, Akwa-Ibom State, Calabar, Cross Rivers State and Ambrose Ali University Ekpoma, Edo State.

He has supervised over 200 undergraduate students' projects, and over 70 postgraduate students' theses, including two PhD theses, Dr

Ejiro Akponah a lecturer in the Department of Microbiology, Delta State University and Mrs. Funmi Williams. He is currently supervising many more undergraduate (B.Sc) and postgraduate (M.Sc and PhD) student projects and theses respectively.

His love for education knows no bound. To improve the infrastructure and the learning environment in the University of Port Harcourt Demonstration Secondary School (UDSS), he electrified four class rooms and donated and installed eight fans (two sets of ceiling fans for each of the class rooms) early in 2011. He was commended by both the Parents Teachers Association and the school management for the action. He is currently representing Senate in the Board of Governors of the institution.

He has been very active in University of Port Harcourt alumni activities. He was the chairman of the University of Port, Harcourt Alumni Association, River State Chapter and a member of the Expanded National Executive, from 2004-2009. From 2002-2004 he was the association's Project Manager. As project manager, he initiated the concept that led to the design and construction of the Goodluck Jonathan Hostel. He and the then Alumni Chairman Mr. P. C. Nwabuzor supervised the building of this structure from foundation to lintel level, through donations from Patrons of the Alumni Association especially the Government of Rivers State under the former Executive Governor, Dr Peter Odili.

He is a Christian and a member of a number of Christian organizations including the Students Christian Movement (SCM) of Nigeria and the Full Gospel Business Men Fellowship, Ogunu chapter, Warri. In 1988-1990 he served as vice-chairman of the Graduate Students fellowship of the University of Port Harcourt. From 1989-2012 he served as the President of SCM Alumni Fellowship, University of Port Harcourt Chapter. In 1995, he was elected as Male staff representative in the Chapel Management Committee of Our Saviour's Chapel (OSC,) University of Port Harcourt. He was elected Peoples Warden in 1997. From 1999 to 2001 he was elected Service Warden. He was elected Men's Leader in 2004. A position he held for two terms 2004-2006, 2006-2008. In 2005 he was made a Lay Reader of the Anglican Communion of Nigeria. From 2010-2011 he was appointed Harvest chairman of the church. During his tenure the church's Harvest proceeds rose to all time heights.
He is happily married to his lovely wife Mrs. Elizabeth Ekenta Odokuma and together they are blessed with four lovely children, Ogaga, Uyota, Eguono and Ohore.

Prof. Francis David Sikoki